Energy Options and Health Benefits: China Case Study

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CONTENTS

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NOTATION

Acronyms and Abbreviations

API	Air pollution index
BAU	Business as usual
BC	Black carbon aerosol
BCHP	Buildings cooling heating & power
CCP	Climate Change Policies
CO	Carbon monoxide
CO_2	Carbon dioxide
CRF	Concentration-Response Function
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
HC	Hydrocarbon
LEAP	Long-range Energy Alternatives Planning System
LPG	Liquefied petroleum gas
NERL	National Renewable Energy Laboratory
NOx	Nitrogen oxides
OC	Submicron organic carbon aerosol
PCP	Pollution Control Policies
PM	Particulate matter
$PM_{2.5}$	Particulate matter with diameters of 2.5μm or less

PM_{10}	Particulate matter with diameters of 10μm or less
RMB	Chinese currency, 1RMB = 0.128 U.S. $
SEPA	State Environmental Protection Administration
SO_2	Sulfur dioxide
TSP	Total suspended particulate
WHO	World Health Organization
WTP	Willingness to Pay

Units of Measure

GJ	giga-joule
kg	kilogram
kt	kiloton
m^3	cubic meter
Mt	million ton
t	ton
μg	microgram

CHAPTER 1 INTRODUCTION

1.1 Background

The Energy Options and Health Benefit study in China was initiated pursuant to a Statement of Intent (SOI) signed by Minister Xie Zhenhua of SEPA and Administrator Carol Browner of EPA in April 1999, in Washington, D.C. This project was one of ten projects initiated at that time in conjunction with the China-U.S. Forum on Environment and Development. The goal of the project was to quantify the benefits, including reductions of greenhouse gases, of energy and transport programs designed to reduce air pollution and protect public health in China. The first component of this project was a case study of air pollution, public health and greenhouse gas benefits of clean energy and transport strategies for Shanghai, China. The second component involved the preparation of a similar case study for Beijing, China. The third component, the results of which are the focus of this report, is a preliminary national assessment of urban air pollution, public health, greenhouse gas, and economic benefits of clean energy and transportation policies and strategies for China. Finally, the fourth component will focus on the effects of "Total Emission Control" policies on energy consumption, air pollution, public health and greenhouse gas benefits in China.

1.2 Objective

The overall objective of the work embraces an integrated analytical framework and approach. One of the key elements of an integrated co-benefits approach is to encourage the consideration and analysis of strategies and/or technologies that benefit local air quality as well as the global climate and to analyze these strategies in an integrated framework.

The work analyzes these strategies/technologies for the "co-benefit" potential, as it is important to develop a range of integrated strategies that take into account both air quality and greenhouse gas (GHG) concerns.

In this study, potential energy policies are classified into several categories. The co-benefits of these energy policies are quantified by the methodology developed under the integrated framework. The results of this study could provide scientific support for a comprehensive air pollution control policy making in China.

1.3 Research activities

The framework of this study is illustrated in Figure 1-1.

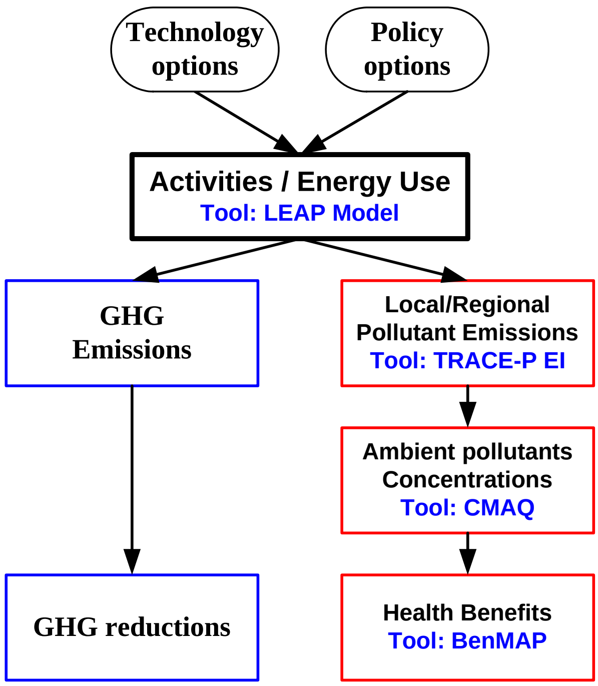


Figure 1-1 Framework of the study

The sectoral scope of the analysis includes: agriculture, industry, power plants, construction, transportation, commercial and household. The geographic scope covers the whole of China. Four time steps are considered: 2001 (Base Year), 2005, 2010, 2020 and 2030, and the environmental emissions evaluated are SO_2, NOx, PM_{10} and CO_2.

1.4 Project participants

The project implementing agencies include: SEPA (project oversight and guidance), Department of Environmental Sciences and Engineering, Tsinghua University (energy options and environment effects, cost-benefit analysis), and School of Public Health, Beijing Medical University (health effects).

EPA and SEPA share overall management and coordination responsibilities for this project. The two parties designate the National Renewable Energy Laboratory (NREL) and Tsinghua University as lead implementing partners in the project. EPA and SEPA, in consultation with each other, guide the scope and direction of this project and provide the management support necessary to make it successful. EPA and

SEPA review all work plans, milestones, interim products and final products from the implementing partners. The technical details of how the national assessment shall be implemented are laid out in the Scope of Work between NREL and Tsinghua University. Both government agencies are in agreement with the activities and schedules outlined in the document. In addition to technical assistance and management, EPA is also providing financial assistance to China for this project.

CHAPTER 2 CURRENT STATUS OF ENERGY USE AND AIR POLLUTION

2.1 Rapid Economic Development

Since the introduction of economic reform and opening policies, the Chinese economy has experienced rapid and significant growth. The annual GDP growth rate reached 8-9% from 1978 to 2004. In 2002, China's GDP exceeded 10 trillion RMB (1RMB = 0.128 USD), as Figure 2-1 shows. In 2004, the GDP per capita in China was 10,561 RMB.

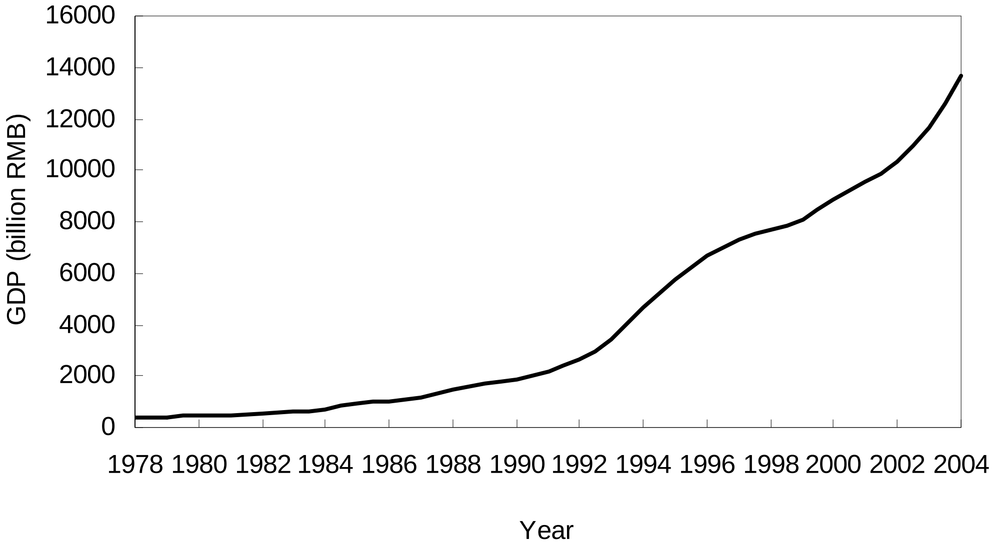


Figure 2-1 Historical GDP Growth in China (Sources: China Statistical Abstract 2005)

After China adopted the policy of reform and economic liberalization, a cross-century economic development strategy was developed to realize modernization in three stages. The goals of the first and second stages were to solve the problems of food and clothing of the entire Chinese people and to enable them to live a relatively comfortable life. In addition, China set the goal of doubling the GDP level of the 1980s during the first stage and increasing GDP by four times the 1980s level by the end of the 20^{th} century. By achieving a level of economic wealth for its citizens, China has basically accomplished the targets of the second stage of its three-stage modernization process. Presently, the objective of the third stage of economic development in China is to attain the level of moderately developed countries by the middle of this century (around 2050), which means that GDP per capita will reach $25,000 per capita based on purchasing power parity (PPP).

In late 2002, China set the goal of building a well-off society by 2020. The 16th

National Congress of the Communist Party of China (CPC) further stated that GDP in 2020 should be four times the level of GDP achieved in 2000, with peoples' standard of living reaching the well-to-do level and economic industrialization realized. The Chinese government also recently set the goal of building a harmonious society. All these objectives demand sustained, fast GDP growth over the next 20 years.

Many researchers have studied China's future economic development and developed different development scenarios. Most of these scenarios are based on the common belief that over the next 20 years China will continue to develop its economy at a high growth rate, the economic gap between China and developed countries will be further reduced, and China will become one of the top economic countries in the world. Figure 2-2 shows some of the primary results of these GDP projection studies. According to these projections, China's annual GDP growth rate will be about 7% over the next 20 years.

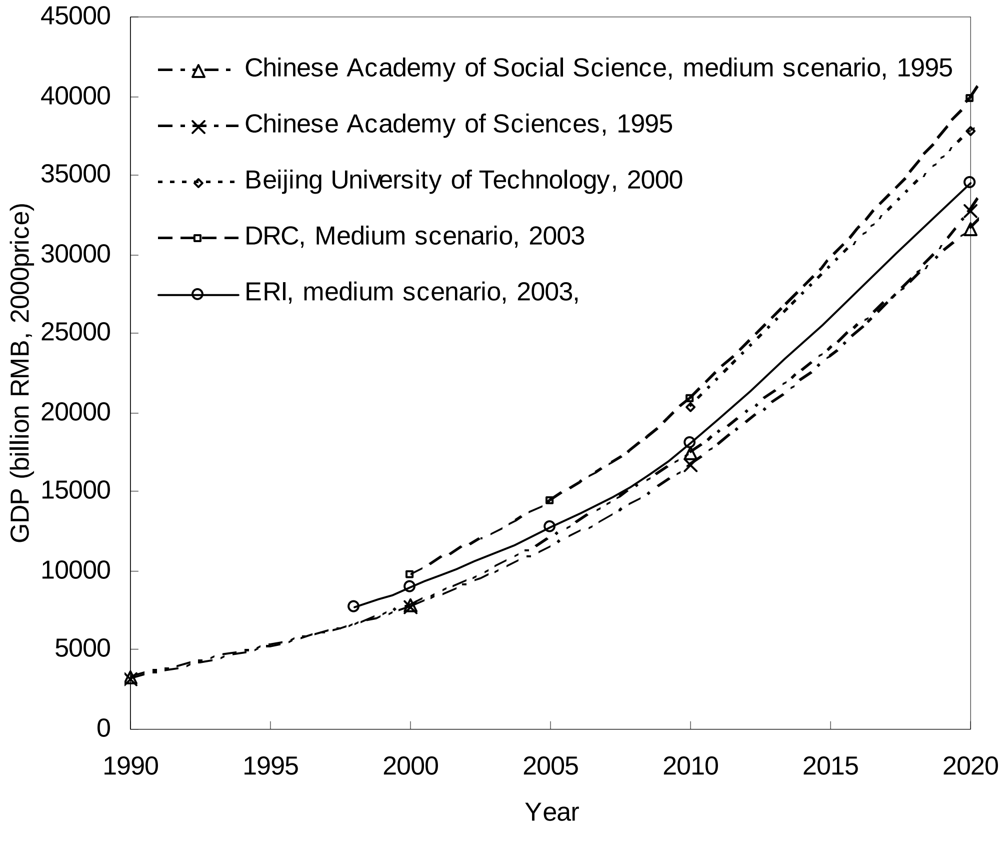


Figure 2-2 Economic Development Trend and Predictions for China

2.2 Energy consumption status

With the rapid development of the Chinese economy, total energy consumption is rising rapidly. In the last two decades of the 20th century, China took a variety of measures to ensure adequate energy supply to meet social and economic development needs. These efforts paid off, and the Chinese economy quadrupled in size while its overall energy consumption only doubled. Although China's energy consumption of 29.3 Gigajoules (GJ) per capita in 1990 was lower than the world average (?) (61.5 GJ per capita) and far lower than that of the U.S. (333.7 GJ per capita) during the same time period, China has become the second largest energy consumer in the world after the U.S., due to the overwhelming increase in energy consumption. In 1980, the overall energy consumption of China was 17.6 billion GJ. In 2000, that figure increased to 38.1 billion GJ. Figure 2-3 shows the total consumption of primary energy in China from 1980 to 2004. From 2000 to 2004, China's energy consumption demonstrated even stronger growth momentum. During this period, the overall energy consumption increased by 19.6 billion GJ, representing an annual increase of 10.8%, The elasticity coefficient[1] with economic development was 1.16. These numbers show that it will become increasingly difficult for China's energy supply to meet the demands of economic development. Because China is entering into the period of industrialization of heavy industry, the majority of the dominant industries in the national economy are still heavily energy-consuming. This generates urgent needs for future energy supply. If China accomplishes economic modernization by the middle of the 21st century, it must find a new way to achieve economic growth with lower energy and resource consumption per capita compared to the developed countries.

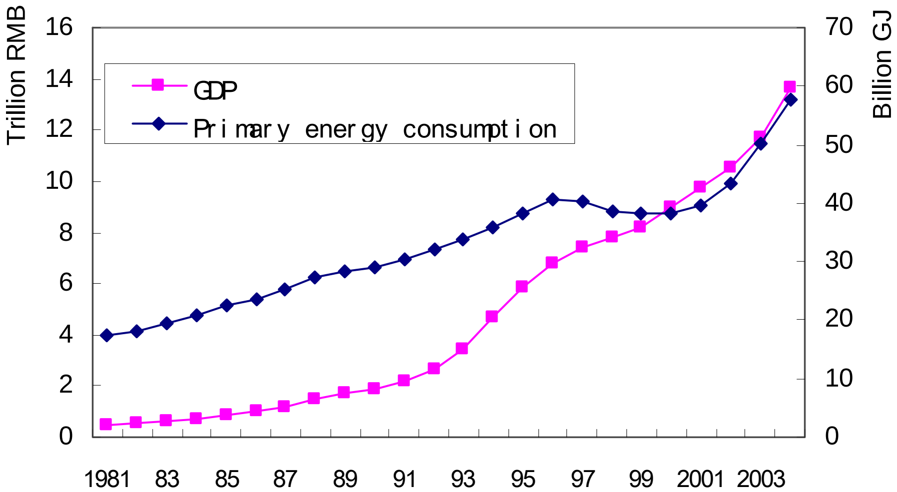


Figure 2-3 Total Consumption of Primary Energy in China

(Sources: China Statistical Yearbook 2003 and data from the official website of China's State Statistical Administration)

2.3 Air quality status

In 1996, China revised its Atmospheric Ambient Quality Standards, as shown in Table 2-1. When the pollution levels of annual average NOx concentration between 1995 and 2001 were analyzed, the 1982 standards were used for 1995 pollutant

[1] Elasticity coefficient: the ratio of the increment of energy to the increment of GDP

concentrations. New standards were used for pollutant concentrations beginning in 1996.

Table 2-1 1996 China National Ambient Air Quality Standards (mg/m^3)

	Averaging time	Class I	Class II	Class III
TSP	Daily	0.12	0.3	0.5
	Annual	0.08	0.2	0.3
PM_{10}	Daily	0.05	0.15	0.25
	Annual	0.04	0.1	0.15
SO_2	Daily	0.05	0.15	0.25
	Annual	0.02	0.06	0.1
NO_2	Daily	0.08	0.08	0.12
	Annual	0.04	0.04	0.08
NO_x	Daily	0.1	0.1	0.15
	Annual	0.05	0.05	0.1
CO	Daily	4	4	6
O_3	hourly	0.12	0.16	0.2

Note: The Class I standard is for natural reserves, national parks, and other protected areas. The Class II standard is for urban residential, commerce-traffic-resident mixed, common industrial, and rural areas. The Class III standard is for special industrial areas.

Since the 1980s, the vehicle population in China has continually increased. At the same time, air pollution from cars has seriously threatened China's air quality, especially in urban areas. Although the main type of the air pollution in China nationwide is currently coal smoke pollution, the dominant pollution source in many cities is transforming from stationary source emissions to mobile source emissions.

In China, the major energy source is coal, which accounts for 70-75% of the national total energy consumption. Thus, urban air pollution in China is mainly caused by coal combustion. Table 2-2 shows the overall situation of urban air quality from 1998 to 2003 based upon the Chinese Environment Quality Report.

Table 2-2 Urban Air Quality from 1998 to 2003

Year	1998	1999	2000	2001	2002	2003

The number of the cities monitored	322	338	332	341	343	340
The percentage of the cities whose air quality meets the Class II standard(%)	27.6	33.1	34.9	33.4	34.1	41.7
The percentage of the cities whose air quality meets the third-level standard but is worse than the Class II standard (%)	28.9	26.3	30.1	33.4	34.7	31.5
The percentage of the cities whose air quality is worse than the Class III standard (%)	43.5	40.6	34.9	33.1	31.2	26.8

See Table 2-1 for National Ambient Air Quality Standards.

In 1998, 27.6% of the 322 cities monitored across China recorded urban environmental air quality that met the Class II standard and 43.5% of cities' air quality was worse than Class III, indicating that nearly half of the cities were suffering from serious urban air pollution. As the national and local government make efforts to control air pollution, the percentage of cities meeting Class II air quality standard is increasing. In 2003, the air quality of 41.5% cities met the Class II standards, but 58.5% cities exceeded Class II standards, half of which even exceed the Class III standard. Urban air pollution is still very serious.

Particulate matter is the main pollutant affecting urban air quality. In 1999, total suspended particulate (TSP) was the pollutant for which the standard was most often exceeded in China's urban air. For 60% of the cities surveyed, the annual average TSP concentration exceeded the national Class II standard. In 2003, The PM_{10} concentration in 54.4% cities exceeded the national Class II standard. Cities seriously polluted by PM are mainly located in Northern China, where heavy industry is based or heavy sand storms occur. In 1999, the SO_2 concentration of 28.4% cities exceeded Class II national standards. This percentage dropped to 25.6% in 2003. The heavily SO_2 polluted areas are located in Shanxi, Shandong, Henan, Hunan, Shannxi, Gansu, Guizhou, Sichuan, and Chongqing, where key electricity generation is based or high levels of surface coal mining occur. NOx pollution occurred in cities with populations larger than 1 million. Vehicle emission pollution is serious in Beijing, Shanghai, and Guangzhou. In addition, as motorization progresses, the urban atmosphere is polluted by both coal burning and vehicle emissions.

Following the adoption of various atmospheric pollution control measures by both state and local governments in recent years, annual daily concentrations of TSP and SO_2 exhibited downward trends. The annual daily average concentration of TSP is gradually approaching the national Class II standard, and SO_2 has met the national Class II standard in most areas. Before 2001, the pollution index of NOx was much higher, indicating the heavy pollution resulting from vehicle emissions. In 2001, China adjusted the measurement index of NOx by changing the index to NO_2 so the NOx index standard can be met more easily than the TSP and SO_2 index standards. However, since the vehicle population in China will grow rapidly, the NOx concentration will probably increase.

Nitrogen oxides in cities are primarily from vehicle emissions. This pollution is as severe as SO_2 and TSP in the whole country. Table 2-3 provides the NOx concentration in Chinese cities. There were differences between northern cities and southern cities in both concentration range and average. On the whole, the annual average of the concentration in northern cities was a little bit higher than southern cities. Detailed information is in Table 2-3.

Table 2-3 Annual Average Statistics on NOx Concentration in Chinese Cities (mg/m^3)

Year	Cities monitored	National NOx concentration		NOx concentration in northern cities		NOx concentration in southern cities	
		Range	Average	Range	Average	Range	Average
1995	88	0.012-0.129	0.047	0.017-0.123	0.053	0.012-0.129	0.041
1996	88	0.007-0.152	0.046	0.029-0.117	0.055	0.022-0.152	0.046
1997	94	0.004-0.140	0.045	0.013-0.133	0.049	0.004-0.140	0.041
1998	96	0.008-0.151	0.045	0.011-0.151	0.049	0.008-0.124	0.041
1999	97	0.007-0.140	0.045	0.007-0.140	0.048	0.007-0.113	0.042
2001	93	0.011-0.071	0.036	0.015-0.071	0.033	0.011-0.071	0.033
2002	96	0.010-0.076	0.035	0.013-0.076	0.037	0.01-0.064	0.033

Note: From 2001, China began to monitor NO_2 instead of NOx.

During 1995 and 2001, the cities with NOx concentrations exceeding Class II standards accounted for 1/3 of the measured cities. The NOx concentrations in Beijing and Guangzhou frequently exceeded Class III standards. Table 2-4 provides information on the number of cities for which air quality data are collected and their situations in regard to the three Chinese standards of NOx concentrations.

Table 2-4 Situation of Exceeding NOx Standards in Chinese Cities

Year	The number of cities collecting air quality data	Cities exceeding any standard		Cities exceeding Class II standard		Cities exceeding Class III standard		Cities exceeding Class III standard
		Number	Exceeding standard rate (%)	Number	Exceeding standard rate (%)	Number	Exceeding standard rate (%)	
1995	88	32	36.4	29	33.0	3	3.4	Beijing, Guangzhou, Lanzhou[1]
1996[2]	88	27	30.7	25	28.4	2	2.3	Beijing, Guangzhou
1997	94	32	34.1	29	30.9	3	3.2	Beijing, Guangzhou Shanghai
1998	96	32	33.3	29	30.2	3	3.1	Beijing, Guangzhou Shanghai
1999	97	32	33	29	29.9	3	3.1	Beijing, Guangzhou Taiyuan
2001[3]	93	33	35.5	33	35.5	0	0	/
2002	96	32	33.3	32	33.3	0	0	/

Notes: 1. According to "Atmosphere Quality Standards" GB3095-82, three cities were above Class II standards in 1995.

2. "Ambient Air Quality Standards" GB 3095-1996 was put into effect in 1996.

3. From 2001, NO_2 became standard.

CHAPTER 3 ENERGY CONSUMPTION TRENDS IN MITIGATION SCENARIOS

This chapter presents the methodology for deriving the energy supply and demand trends in China for the next 30 years using the scenario analysis method. In contrast to other projection methods or market research methods, the scenario analysis method does not involve extrapolation of the current status. Instead, it assumes several future possible situations and provides optimized strategies to deal with the complicated problems which will emerge in the future. This chapter analyzes the energy system in China and establishes the scenario analysis frame for energy demand and supply over the next 30 years for realizing sustainable energy supply, promoting clean energy supply, reducing GHGs, and improving the urban air quality. In the later chapters, the effects of each scenario on air quality and human health are further analyzed.

3.1 Scenario definition and description

Three scenarios are involved in this research. A business as usual (BAU) scenario will be taken as a base scenario, and two policy scenarios will estimate the effects of different sorts of policies.

3.1.1 Business as usual (BAU)

The business as usual scenario uses the Energy Research Institute's 2003 projection on basic economic and energy information.

Table 3-1 Projection of GDP growth rate and population in China

	2001	**2010**	**2020**	**2030**
GDP growth rate, %	7.2	6.7	5.5	5.5
GDP per capita, thousand CNY	7,496	13,013	23,332	38,416
Urban population, million	471	606	820	991
Rural population, million	808	772	650	534
Urban housing area per capita, m^2	20.8	29.0	35.0	38.0
Rural housing area per capita, m^2	25.5	31.0	36.0	40.0

In the BAU scenario, GDP will continue to increase rapidly, and energy demand will retain the current high growth trend. Energy consumption in each sector will increase gradually. Although the government will not implement regulations requiring industries to save energy, the energy intensity of industries will slowly decrease due to industry structure adjustment, technology improvement, and the consideration of the industries themselves for reducing cost. Accompanying the urbanization process, the proportion of the population living in rural areas will decrease. Energy consumption in rural areas will decrease in spite of improvement in the life quality of rural citizens. Although urban population and quality of life will increase rapidly, the development of standard and material technologies for building insulation could save a large amount of energy, and thus energy consumption in the urban residential sector will increase at a relatively slow speed. The vehicle population will grow greatly, and the energy consumption of the transport sector will continue to increase.

Energy market structure will move toward sustainability. The proportion of homes using biomass in inefficient stoves for cooking and heating needs will decrease rapidly. Coal will remain dominant position in primary energy requirements, but the proportion will fall as consumption of clean fuel greatly increases. Demand for crude oil will increase rapidly with the growth of the vehicle population. The government will take great efforts to develop hydropower and nuclear power plants to protect the environment, and much more natural gas will be used directly in end-use.

3.1.2 Policy scenarios

This research assumes more energy and environmental policies are adopted in the future 30 years and classifies them into two kinds of policies: Climate Change Policies (CCP) and Pollution Control Policies (PCP). Two scenarios are designed based on these two categories of co-benefits policies. The assumptions of the scenarios are listed in table 3-2.

- **Climate Change Policies (CCP)**

In this scenario, it is assumed that the government adopts a series of policies and programs to reduce the emissions of GHGs. Technologies to promote greater efficiency in energy use will be introduced in all sectors, and additional measures will be implemented to encourage the use of gaseous and liquid fuels for residential, commercial, and industrial use.

- **Pollution Control Policies (PCP)**

In this scenario, it is assumed that the government strengthens the pollution control policies. New and stricter emissions standards will be released and executed earlier than in the BAU scenario. Advanced technologies to reduce the emissions of SO_2, NOx and primary PM will be diffused.

Table 3-2 Assumptions in scenarios

Scenario	Assumptions
BAU	➢ Electricity and gas fuel are dominant energy uses in urban residential. ➢ Energy conservation laws and related laws are implemented well. ➢ For mobile sources, EUROIII standards will be put in force in 2008, EUROIV in 2012, and more strict standards implemented in 2018 and 2025. ➢ Government policies are successful in "two controlled zones": New power plants must install FGD after 2000, and NOx control technologies begin to be wildly used from 2015.
CCP	In addition to BAU…… ➢ Energy intensity in industrial sector decreases more rapidly. ➢ More energy saving appliances are used in residential sector. ➢ Energy conservation standards for buildings greatly improve, and more dispersed heating supplies are replaced by centralized ones. ➢ Fuel economy of automobiles increases more. ➢ Efficiency of electricity plants and heat boilers increase more.
PCP	In addition to BAU…… ➢ Conversion of small power plants into larger ones with FGD is accelerated, and NOx control technologies begin to be wildly used after 2012. ➢ Efficiency of SO_2 and NOx control in industrial sectors is improved more. ➢ PM control is more focused. More ESP and baghouse filters are installed. ➢ For mobile sources, EUROIII standards will be put in force in 2008, EUROIV in 2010, and more strict standards in 2015 and 2020.

Based on the above assumptions of policies, this research designs two scenarios, as shown in Table 3-3.

Table 3-3 Definition of the scenarios

	BAU	CCP	PCP
BAU	√		
Scenario 1	√	√	

Scenario 2	√	√	√

3.1.3 Measures under policies

Based on the policies, various measures will be implemented and impact the energy system in different aspects, including energy structure, energy efficiency of industry, energy intensity of buildings, and emission factors of all sources. Table 3-4 summarizes the measures that are to be implemented for each scenario. The most important indicators for the measures are listed as well.

Table 3-4 Characteristics of Future Energy and Environmental Policies

Scenarios	Future Energy and Environment Policies	Indicators	Indicators in BAU
CCP	**Households energy saving**	Energy saving lamp increases to 45% in 2010 and 70% in 2030 in urban households, and 24% in 2010 and 53% in 2030 in rural households.	Urban: 34% in 2010, and 45% in 2030 Rural: 20% in 2010 and 40% in 2030
	Industry energy saving	Energy intensity decreases: Iron and steel: 1.72% per year, Nonmetal minerals: 3.2% per year, Chemical products: 3.5% per year, Manufacturing and processing: 3.5% per year, etc.	Iron and steel: 1.62% per year Nonmetal minerals: 2.9% per year Chemical products: 3.25% per year Manufacturing and processing: 2.5% per year, etc.
	Building energy saving *	Public building: Terminal heating loading (W/m^2) decreases to 54.4% of current value in 2010, and 32.8% in 2030. Residential building: Terminal heating loading (W/m^2) decreases to 55.5% of current value in 2010, and 36.1% in 2030.	Public building: 68.4% in 2010 and 51.8% in 2030 Residential building: 70.6% in 2010 and 54.0% in 2030.
	Vehicle energy efficiency improvement	Energy efficiency of light buses and cars increases 87% before 2030	Energy efficiency increases 46% before 2030
PCP	**Improvement of rural cooking condition**	Biomass consumption in cooking decreases to 50% in 2010 and 19% in 2030	53% in 2010 and 26% in 2030.

	Switching heating boilers and stoves	Urban: 24% of heating boilers uses natural gas in 2010, and 50% in 2030. Rural: Biomass stoves contribute 50% in 2010, and 10% in 2030	Urban: 20% in 2010, and 45% in 2030. Rural: Biomass stoves contribute 45% in 2010, and 5% in 2030
	Vehicle emission standard	Implement EURO IV in 2010, and EURO V in 2015	EURO IV in 2012, and EURO V in 2018
	Two control zone policy	New power plants install FGD (flue gas desulfurization), and power plants over 30 years old are eliminated. New power plants install SCR (Selective Catalytic Reduction) from 2012.	New power plants install FGD. New power plants install SCR (Selective Catalytic Reduction) from 2015.
	PM control in industry	Baghouse installed with 20% of CFB (Circulating Fluidized Bed) boiler in 2010 and 75% in 2030; and with 2% of grate furnace in 2010,and 30% in 2030	With CFB: 15% in 2010 and 60% in 2030; With grate furnace: 1% in 2010, and 20% in 2030

*: Average value in China. In LEAP model, public building is classified into 5 types: office, hospital, school, hotel, and others; residential building is classified into rural and urban, and then subclassified by regions.

3.2 Methodology of LEAP

In this portion of the research, the LEAP model was used to develop the energy scenarios. The researched area is the mainland of China, and the time period is from 2001 to 2030. The energy demand, energy supply and investment under different scenarios is calculated.

3.2.1 LEAP Model

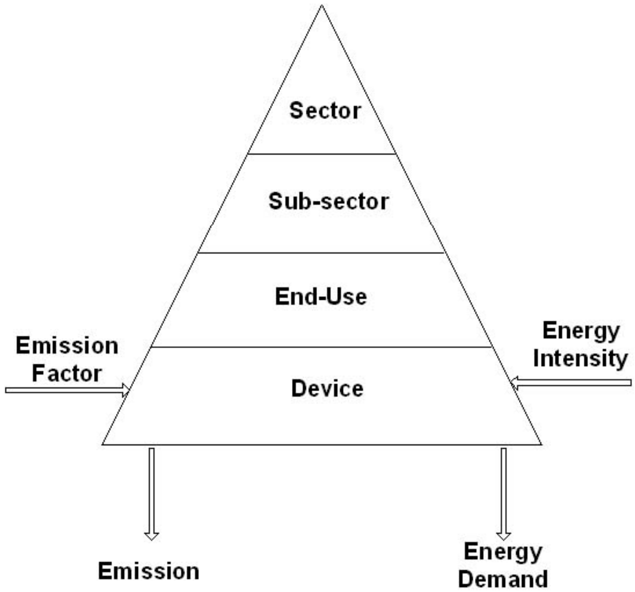


Figure 3-1 Methodological Framework of LEAP model

The Long-range Energy Alternatives Planning system (LEAP) is a scenario-based energy-environment modeling tool developed at the Stockholm Environment Institute (SEI), Boston. Scenario development is based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology and so on. Based on an end-use driven scenario analysis, the computer system is used to analyze current energy use and to simulate alternative energy futures. LEAP has flexible data structures. Within the LEAP framework, the energy system is divided into several levels of activity that affect energy consumption. These levels are sector, sub-sector, end-use and device/fuel. Parameters for energy intensity and emission factors for each pollutant are associated with each device/fuel at the bottom level. Based on the bottom-up method, total energy demand and emission levels are calculated. Figure 3-1 shows the framework of LEAP.

3.2.2 Establishment of model structure and collection of the data

This research uses the conventional sector analysis method to establish the model structure. The energy demand system is divided into 6 sectors: residential, industry, public building, transportation, agriculture, and construction. The energy transformation system is divided into 10 sectors: electricity generation, heat supply, gas making, coking, briquette making, biogas making, coal washing, oil refining, oil extraction, and natural gas extraction.

According to the methodological framework in Fig 3-1, each sector is further classified into several sub-sectors, end-use sectors, and end-use equipment/fuel. Figure 3-2 and Table 3-5 show fuel chain structure and the frame structure of the model.

Accurate characterization of the energy system mentioned above requires detailed historical data. Currently, the energy statistical data are separate and non-systematic, and the relevant data are scattered throughout the expansive volume of literature and research reports; therefore, collection of these data requires significant time. The data used in this research mainly comes from China Statistical Yearbook, China Energy Statistical Yearbook, Transportation Statistical Yearbook, Electricity Statistical Yearbook, and many papers and research reports.

The data required in LEAP model mainly include 4 groups: macroeconomic variables, energy demand data, energy supply transformation data, and alternative technologies data. The macro economic variables include urban and rural population, urban and rural population per family, GDP and its composition, urban and rural light intensity, social passenger and freight traffic volume. The energy demand data include each sector's energy demand, energy structure, activity level and energy intensity of terminal equipment, and so on. Energy supply transformation data include product volume of the primary energy, production capacity, structure of feedstock, and efficiency of the energy transformation of each energy transform sector. The alternative technologies data include investment of each kind of technology.

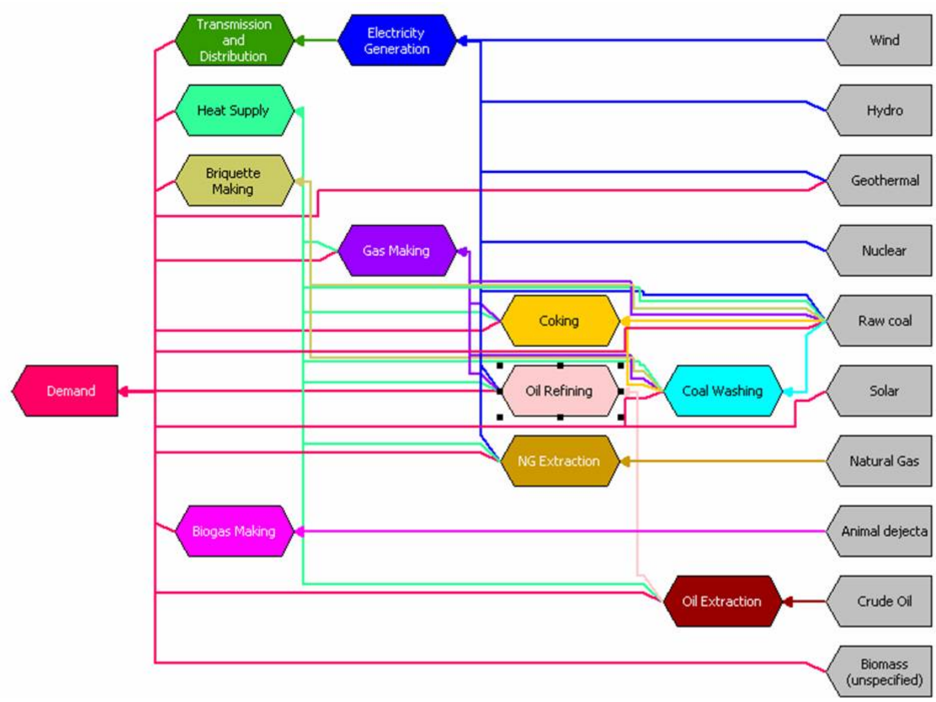


Figure 3-2 Fuel chain structure in LEAP

3.2.3 Developing the scenarios

LEAP model can generate the energy scenarios based on the known or assumed parameters. Base year is the start of all scenarios. The data in the base year come from the published statistical data. Based on the base year, each scenario presents how the energy demand and supply vary with time. The BAU scenario is the comparative object and reference for other scenarios. It includes policies that the government has already considered and implemented and the future effects of these policies.

Other scenarios provide packages or series of energy policy alternatives. These policies are expressed by the assumptions of the energy, technologies, and activity parameters in the model. For example, in the scenario of climate change policies, the model can designate the percentage as well as the efficiency of BCHP (Buildings cooling, heating & power), traditional coal heating, NG, and electricity in the urban residential energy demand for heating in different year. Changes in the distribution of technologies as well as changes in efficiency presented and quantified the effects of energy efficiency policies and shifting heating technologies in the residential sector.

Table 3-5 Structure of energy demand sectors in LEAP

Sector	Sub-sector		End-use	Device/Fuel
Residential	Urban		Lighting	Ordinary lamp, Energy-saving lamp
			Air Conditioning	Old device, Efficient device, Ultra-efficient device
		Home appliance	Refrigerator	Old device, Efficient device, Ultra-efficient device
			Washing	Tumbling, Wave rounds
			TV	Big, Middle, Small
			Radiator	Electricity
			Drain Lampblack	Electricity
			Fan	Electricity
			Others	Electricity
			Cooking & Hot Water	Coal, Coke oven gas, LPG, NG, Electricity
		Heating	Northern Area	Centered heating, BCHP, Decentralized coal, Small stove, NG, Electricity
			Intergrading Area	BCHP, Decentralized coal, NG, Electricity
			Southern Area	Electricity
	Rural		Lighting	Ordinary lamp, Energy-saving lamp
			Air Conditioning	Old device, Efficient device, Ultra-efficient device
		Home appliance	Refrigerator	Old device, Efficient device, Ultra-efficient device
			Washing	Tumbling, Wave rounds
			TV	Big, Middle, Small
			Fan	Electricity
			Others	Electricity
			Cooking & Hot Water	Biomass, Biogas, Coal, LPG, Others
		Heating	Northern Area	Decentralized coal, Small stove, Electricity, Biomass
			Intergrading Area	Decentralized coal, Small stove, NG, Electricity

			Southern Area	Electricity
Industry	Iron &Steel, Nonferrous Metals, Nonmetal Mineral, Chemical Products, Petroleum Processing & Coking, Paper Making, Manufacturing, Processing, Mining of Energy Resources, Supply of Tap Water			Raw coal, Cleaned coal, Other washed coal, Coke, Coke oven gas, Other coking products, Other gas, Heavy oil, Kerosene, Diesel, NG, Heat, Electricity, Crude oil, Other petro products, LPG
Public Building	Office		Heating	Centered heating, BCHP, Coal boiler, NG boiler, Electricity, Geothermal
	Hospital		Air Conditioning	Electric central, Gas central, Electric decentralized, GSHP, Ice storage
	School		Lighting	Traditional, Efficient
	Hotel		Others	Electricity
	Others			
Transportation	by Vehicle		Heavy truck, Middle truck, Light truck, Mini truck, Heavy bus, Middle bus, Light bus, Mini bus, Car	Diesel, Gasoline
			Motorcycle	Gasoline
	Others	Passenger	Railway	Diesel locomotive, Electricity locomotive
			Water	Diesel Vessel, Heavy oil vessel
			Air	Passenger plane
		Freight	Railway	Diesel locomotive, Electricity locomotive, Steam locomotive
			Water	Diesel vessel, Heavy oil vessel
			Air	Passenger plane, Freight only aircraft
			Pipeline	Raw coal, Diesel, Electricity
Agriculture				Raw coal, Coke, Kerosene, Diesel, Heavy oil, Electricity
Construction				Raw coal, Coke, Crude oil, Kerosene, Diesel, Heavy oil, NG, Electricity

3.3 Results and Analysis

3.3.1 Energy Consumption Trends

Energy demand and fuel mix for BAU and two alternative policy scenarios in the future years is calculated by the LEAP model. The results of years 2010, 2020, and 2030, as well as energy consumption in the base year (2001), are listed in Table 3-6.

Table 3-6 Final energy demand of 3 scenarios, 2001-2030 (Unit: Billion GJ)

	2001	2005	2010	2020	2030	2030/2001	Case(2030)/BAU
BAU							
Coal products*	17	19	20	21	24	1.36	1.00
Oil products**	8	11	14	20	28	3.33	1.00
Natural gas	1	1	2	4	7	6.96	1.00
Heat	2	3	3	6	8	4.11	1.00
Electricity	5	6	7	11	15	3.13	1.00
New energy***	0	0	0	0	1	18.50	1.00
Biomass	8	8	7	4	2	0.24	1.00
Total	**41**	**47**	**53**	**67**	**84**	**2.01**	**1.00**
Scenario 1							
Coal products	17	18	18	19	20	1.13	0.83
Oil products	8	10	14	19	26	3.17	0.95
Natural gas	1	1	2	4	6	6.14	0.88
Heat	2	3	3	5	6	3.01	0.73
Electricity	5	6	7	10	12	2.67	0.85
New energy	0	0	0	0	1	13.00	0.70
Biomass	8	7	6	3	2	0.18	0.76
Total	**41**	**46**	**49**	**60**	**72**	**1.75**	**0.87**
Scenario 2							
Coal products	17	18	18	17	19	1.07	0.79
Oil products	8	10	14	19	26	3.13	0.94
Natural gas	1	1	2	4	6	6.07	0.87
Heat	2	3	3	5	6	2.81	0.68
Electricity	5	6	7	10	12	2.64	0.84
New energy	0	0	0	0	1	18.50	1.00
Biomass	8	7	5	3	1	0.17	0.69
Total	**41**	**45**	**49**	**58**	**71**	**1.70**	**0.85**

* Coal products include coal, cleaned coal, coke and coke oven gas.
** Oil products include crude oil, gasoline, diesel, fuel oil and LPG.
***New energy includes geothermal, solar, wind, etc.

Two indexes are calculated in Table 3-6. One is the ratio of fuel and energy consumption in 2030 to 2001; the other is the ratio of fuel and energy consumption in alternative policy scenarios to BAU.

The BAU case forecasts that final energy demand will increase 2.01 times between 2001 and 2030. Consumption of coal products will increase slowly, but heat and electricity, which are mainly transformed from coal in China, will increase faster. Oil and natural gas use will increase significantly, while biomass will decline 76% over the next 30 years. Energy structure will become more sustainable and efficient. However, coal (including coal products and heat and electricity transformed from coal) will remain dominant in primary energy demand, contributing 54.54% of total energy resources.

Energy saving in Scenario 1 is very significant, with consumption at 11.44 Billion Gigajoules less than the BAU case in 2030. Scenario 2 is not as effective in energy saving because the main purpose of the policies is to reduce the emission of air pollutants. Scenario 2 does not focus as much on increasing energy efficiency as Scenario 1, and some of its policies even require additional energy consumption for emission control of pollutants (e.g. FGD for SO_2 control and baghouse for PM control).

3.3.2 Impact on Sectors

Figure 3-3 and Figure 3-4 illustrate the energy consumption in each sector from 2001 to 2030 in the BAU case and in Scenario 2. Energy consumption in Scenario 1 has a very similar distribution to Scenario 2.

In the BAU case, energy consumption in the transportation sector increases rapidly due to the large demand for transportation caused by an increasing GDP. Industry remains dominant in the six economic sectors. Energy use in public building also rises due to construction of public use buildings and the need for comfort, which requires more energy for heating in winter and cooling in summer. Energy consumption in the residential sector remains nearly stable. This is because the potential of the largest subsector, heating, to save energy, counteracts the increase in building area. The energy intensity for heating in urban China is more than 3 times higher than advanced countries, and it is much worse in rural China. For example, many rural families use biomass for heating in winter, the energy efficiency of which is only about 15%. When they change their fuel from biomass to coal, natural gas, or other advanced commercial energy, efficiency will dramatically increase.

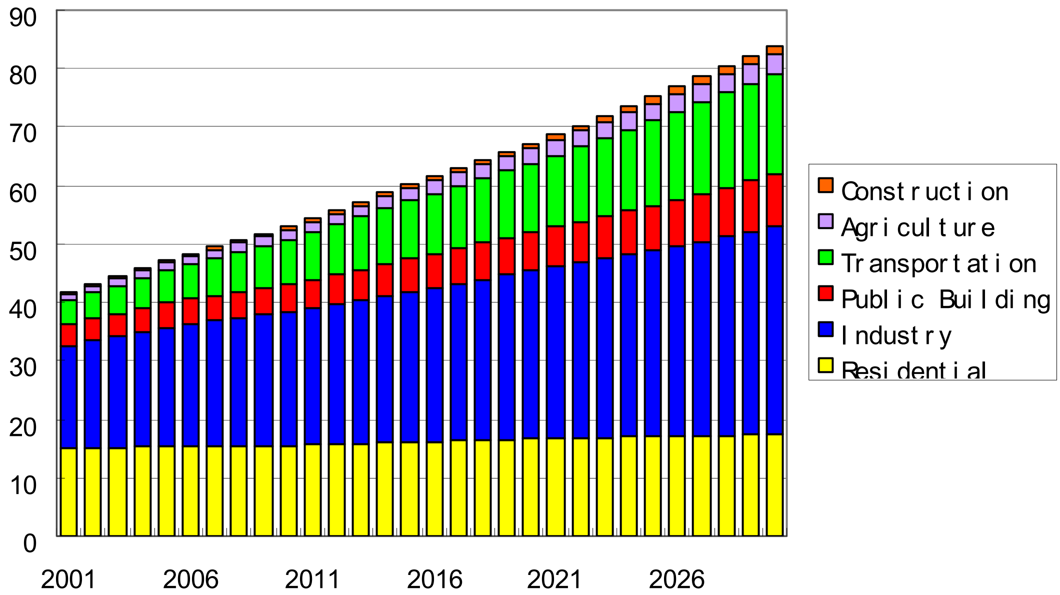


Figure 3-3 Energy consumption in BAU, by sectors (Unit: Billion GJ)

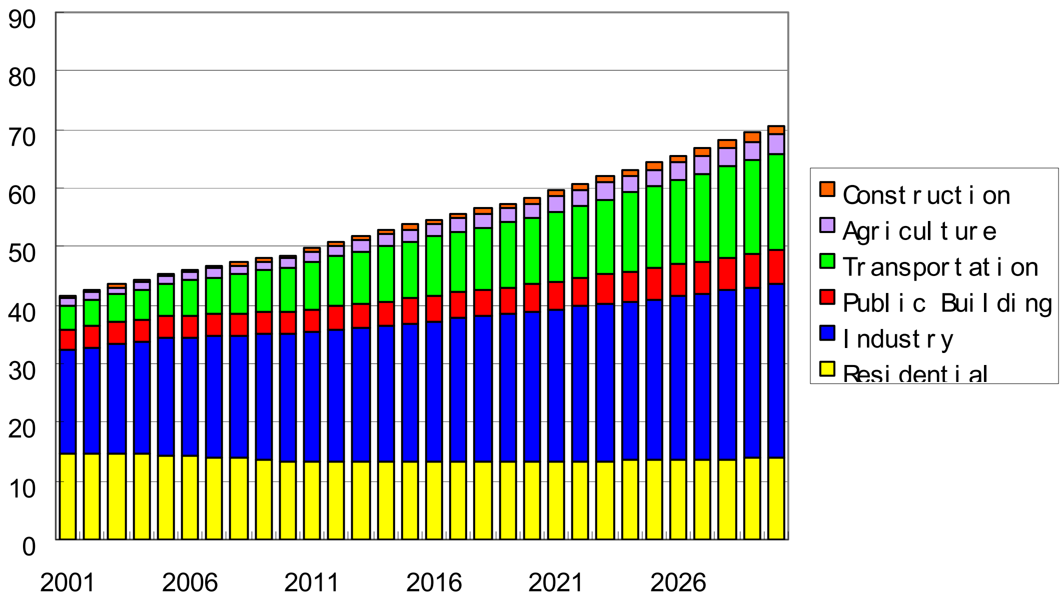


Figure 3-4 Energy consumption in Scenario 2, by sectors (Unit: Billion GJ)

In Scenario 2, energy consumption in each sector is less than the BAU case with the exception of the transportation sector. This is primarily because transportation sector policies in BAU are aggressive when compared with policies for other sectors. Because of China's lack of oil, the government highlights the importance of increasing energy efficiency in transportation, and thus the potential for additional increases in energy efficiency in the transportation sector is not as great as in other sectors. The residential sector is expected to consume a decreasing amount of energy in future years, but this will only happen if policies are implemented well.

CHAPTER 4 LOCAL POLLUTANTS AND GHGS EMISSION

4.1 Emissions calculation in base year

This research uses the TRACE-P inventory method to calculate the emissions for the eight major chemical species, including SO_2, NO_x, CO, CH_4, non-methane volatile organic compounds (NMVOC), submicron black carbon aerosol (BC), submicron organic carbon aerosol (OC), and NH_3. CO_2 is separately estimated. The research area is the mainland of China, divided into 31 provinces. Emissions of pollutants in 2001, 2005, 2010, 2020, and 2030 are calculated for this area. Because meteorological data from 2000 is not accessible, air quality simulation and following validation could not be conducted based on emissions in 2000. Instead of 2000, the year 2001 was chosen as the base year, and energy consumption in BAU is used to calculate the emissions of pollutants. According to the results of LEAP model, the difference in energy consumption among the three scenarios in 2001 is within 1%, which is much less than the uncertainty of air quality model.

4.1.1 Methodology

Figure 4-1 shows the general methodology for the eight major chemical species. In addition, NMVOC emissions are speciated into 19 subcategories based on chemical reactivity and functional groups.

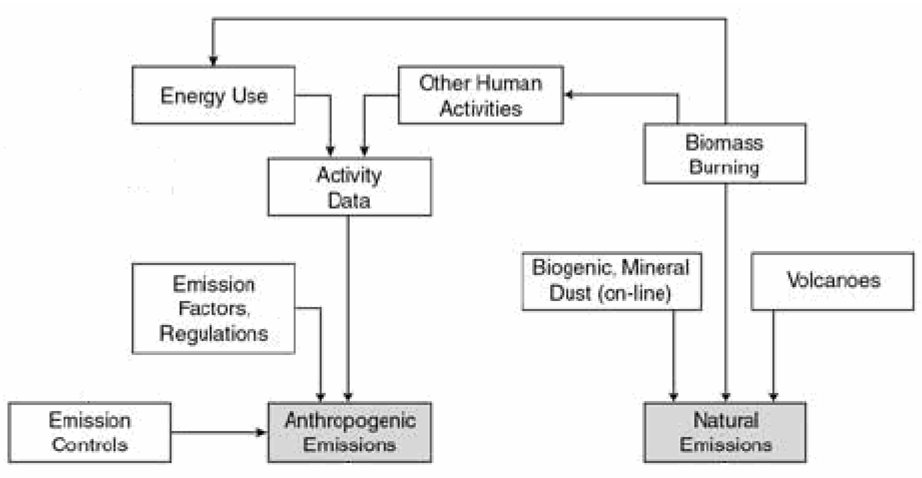


Figure 4-1 Schematic methodology for the development of Chinese emission estimates

Emissions calculated in this research are for anthropogenic sources only, but "open" biomass burning is included because it is largely caused by human activity. Emissions are calculated for all source types believed to contribute significantly to the emissions of a particular chemical species. The detailed emission calculations are aggregated into seven primary source categories: industry, residential, transportation, power generation, agriculture, biomass burning and other.

The emissions of a particular species are estimated as a product of the activity rate, the unabated emission factor, and the removal efficiency of any applied emission abatement technologies, using the following equations:

$$E_{j,k} = \sum_{l}\sum_{m}\sum_{n} A_{j,k,l,m} ef_{j,k,l,m} (1-\eta_{j,l,m,n}\alpha_{j,k,l,m,n}) X_{j,k,l,m,n} \tag{1}$$

Where

j,k,l,m,n species, region, sector, fuel/activity type, abatement technology;

E emissions;

A activity rate;

ef unabated emission factor;

η removal efficiency of abatement technology n;

α maximum application rate of abatement technology n;

X actual application rate of abatement technology n; note that the set of abatement technologies includes a "no-control" case, such that $\sum_{n} X = 1$

The parameter $\alpha_{j,k,l,m,n}$ is used only for NMVOC in this inventory to allow for the fact that emissions are generated by a large number of inhomogeneous sources, and consequently some control options apply only to a fraction of the total activity. In China, there is little abatement technology in place, such that $(1-\eta_{j,l,m,n}\alpha_{j,k,l,m,n})X_{j,k,l,m,n} = 1$, and emissions become simply a product of activity rates and emission factors. Abatement technologies must be considered for large sources of SO_2 in industry and power generation sectors for which relevant regulations are implemented.

4.1.2 Activity rates

Based on the above methodology, a comprehensive picture of energy use by fuel type, sector, and region is developed. Table 4-1 presents basic information on fossil fuel and biofuel energy use in the year 2001 by sector and fuel type used to develop combustion-related emissions. Table 4-2 identifies the other, noncombustion source types that are included in the emission calculations.

A separate approach was taken for transportation emissions because of the need to consider the variety of vehicles in use in China and their widely differing emission rates. Emissions are estimated as the product of the number of vehicles in a province, annual vehicle km traveled, and emission rate in gkm-1 of pollutant emitted. Table 4-3 shows the assumed numbers of each of ten types of vehicles in China.

Table 4-1 Fuel use and vegetation burned in China in 2001

Industry (Million tons)			Domestic (Million tons)			Transport(Million tons)
Coal	Oil	Other	Coal	Biofuel	Other	All fuels
512	42	20	170	476	27	75

Power(Million tons)			Biomass Burned (Million tons)		
Coal	Oil	Other	Savanna /grassland	Forest	Crop residue
676	15	20	52	25	105

Table 4-2 Non-combustion activities included in the inventory

Species	Activities included					
CO_2	Cement production					
CO	Steel production	Pig iron production				
CH_4	Rice cultivation	Animal emissions	Landfills	Wastewater treatment	Coal mining	Leakage from oil and gas extraction and use
NMVOC	Vehicle refueling and evaporation	Oil and gas extraction process	Solvent and paint use	Chemical industry	Miscellaneous industry	Waste disposal
NH_3	Cattle	pigs	Other animals	Fertilizer application	Waste treatment and disposal	Nitrogen fertilizer manufacturing

Table 4-3 Numbers of motor vehicles in China in 2001[a]

Cars		Buses		Trucks				Tractors	Motor -cycles
LDGV (Gas)	LDDV (Diesel)	HDGV (Gas)	HDDV (Diesel)	LDGT (Gas)	LDDT (Diesel)	HDGV (Gas)	HDDV (Diesel)		
6205	773	368	217	9161	969	2075	2129	10124	13754

[a] data are $\times 10^3$

4.1.3 Emission factors

Emission factors were developed from a wide range of sources. Table 4-4 summarizes the ranges of emission factors that were used for fossil fuel and biofuel combustion in different sectors. The ranges presented cover different provinces; typically, the lower end of a range applies to more developed provinces; the upper end of a range applies to less developed provinces.

Emission factors for vehicles were derived using the MOBILE5 model and were determined for each of the ten vehicle categories for China. Emission factors for open biomass burning are shown in table 4-5. Emission factors for CH_4 essentially followed IPCC methodology, with special use of the China Country Study. Emission factors for NH_3 are estimated with livestock emissions adjusted for region-specific production efficiency of milk and meat and fertilizer emissions adjusted for differences in nitrogen losses between temperate and tropical regions. Emission factors for CO_2 based on fuel type, which come from Energy Research Institute of China, are listed in table 4-6. For some source types that are similar in China and the West, U.S. EPA AP-42 emission factors are used.

Table 4-4 Emission factors for fuel combustion [a]

	Industry		Domestic	
	Coal	Oil	Coal	Biofuel
SO_2	0.77-117	0.58-11.6	3.29-54.8	0.66-4.12
NO_x	2.38-6.44	3.35-7.26	1.19-2.24	0.54-0.68
CO	37.6		74	43-77
BC	0.056-0.6	0.25-0.36	0.12-3.7	1
OC	0.0081-0.056	0.19-0.27	0.12-3.00	5

	Transport			Power	
		Oil		Coal	Oil
SO_2		3.17-10.3		3.81-112.6	3.11-11.6
NOx		15.0-58.2		4.59-11.8	2.1-8.54
	LDV	HDV	MC		
CO	(1.0-69.3)	(17.7-135)	(11.5-21.1)		
BC	(0.01-0.19)	(0.02-0.27)	(0.01)		0.36
OC	(0.01-0.13)	(0.03-0.18)	(0.04)		0.27

[a] Emission factors are in gkg^{-1}, except for values in parenthesis, which are in gkm^{-1}

Table 4-5 Emission factors for open biomass burning [a]

Species	Savanna/grassland	Tropical forest	Extra-tropical forest	Crop residue
SO_2	0.35	0.57	1.00	0.40
NO_x	3.90	1.60	3.00	2.50
CO	65	104	107	92
CH_4	2.30	6.80	4.70	2.70
NMVOC	9.73	19.32	27.79	15.70
BC	0.48	0.66	0.56	0.69
OC	3.40	5.20	9.15	3.30
NH_3	1.05	1.30	1.40	1.30

[a] emission factors are in gkg-1.

Table 4-6 Emissions factors for CO_2

Fuel	Coal	Coke	Coke gas	Gasoline	Diesel	Fuel Oil	LPG	Natural gas
Factor (Kg-C/GJ)	24.81	25.27	25.27	18.23	18.66	19.48	16.39	13.43

4.2 Results in base year

The provincial summaries of emissions of each of the eight major species studied are presented in table 4-7. For CO_2, the total emission in China in 2001 is 873,344 kt-C. The major source types contributing to the emissions of each species are showed in figure 4-2.

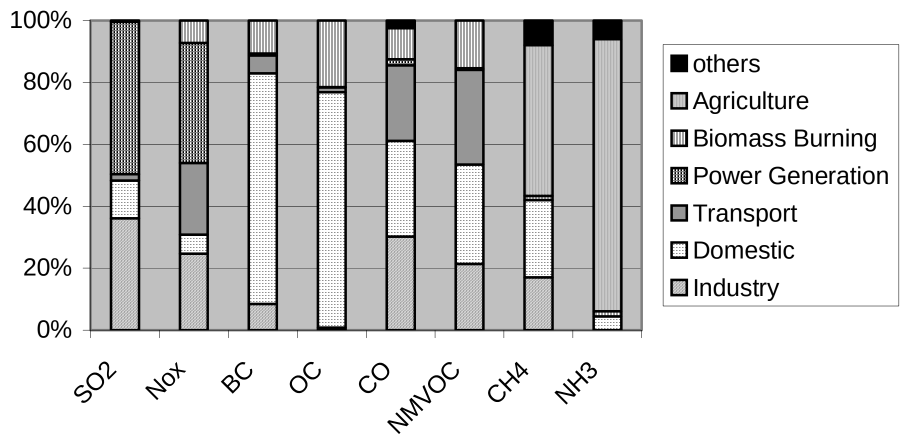


Figure 4-2 Species emissions by emitting sector in China in 2001

Table 4-7 Summary of province emissions of each species in China in 2001

Unit: kt	SO_2	NOx	BC	OC	CO	NMVOC	CH_4	NH_3
Anhui	446.1	347.5	29.8	113.3	6696.2	537.1	1888.3	670.5
Beijing	358.8	228.1	9.4	13.1	3761.0	394.9	277.9	65.8
Fujian	192.8	166.9	19.5	77.1	3522.1	403.8	808.0	334.4
Gansu	438.6	195.1	22.0	59.1	3180.3	261.5	562.0	209.6
Guangdong	845.3	684.8	25.8	73.5	8646.2	1289.2	1884.7	712.2
Guangxi	789.9	213.4	28.3	123.6	3943.1	530.5	1527.6	519.9
Guizhou	1046.6	196.0	48.7	120.8	3298.1	398.5	1084.8	349.8
Hainan	34.8	43.3	2.0	8.1	1282.3	151.3	258.6	78.0
Hebei	1351.3	686.1	62.2	138.3	11736.9	855.7	1546.4	840.4
Heilongjiang	295.7	519.9	51.9	245.4	5763.4	973.4	1446.6	378.0
Henan	1204.9	534.0	60.5	182.9	8934.2	855.9	2207.3	1134.6
Hong Kong	76.3	148.2	0.8	0.8	0.0	109.4	369.6	5.3
Hubei	577.5	531.5	64.1	200.0	7314.1	801.8	1824.8	797.8
Hunan	643.1	371.2	59.7	188.3	5646.7	718.9	2139.7	721.7
Jiangsu	1191.2	693.1	47.5	176.1	8939.6	861.4	2118.1	1006.8
Jiangxi	499.2	233.6	34.3	134.1	3526.5	597.4	1573.6	461.0
Jilin	236.7	338.3	37.6	121.4	4175.0	512.0	806.8	331.9
Liaoning	948.7	720.1	59.0	146.4	7282.4	910.4	1221.1	398.5
Nei Mongol	658.6	497.1	31.6	164.2	5400.2	581.5	1127.7	320.9
Ningxia	251.6	110.4	4.7	14.9	826.8	72.5	205.0	54.6
Qinghai	51.5	94.0	8.5	34.8	1180.6	122.8	349.7	89.6
Shaanxi	883.0	258.4	24.9	72.7	3116.3	350.4	662.5	303.7
Shandong	1967.3	812.4	60.1	197.0	12875.9	1197.8	2214.1	1093.0
Shanghai	517.8	382.9	7.8	8.7	1897.6	390.4	467.8	77.4
Shanxi	1480.5	557.9	26.8	31.9	5960.1	401.8	1818.1	208.3
Sichuan	1712.5	610.1	102.1	340.7	10894.9	1232.1	4524.6	1111.5
Tianjin	388.8	256.2	10.3	16.5	1950.4	260.0	209.3	42.2
Xinjiang	342.3	172.8	31.6	75.8	3613.0	336.9	753.3	253.5
Xizang	15.9	95.8	8.6	53.8	1088.6	171.3	387.3	93.4
Yunnan	396.2	207.7	42.3	147.2	4134.7	594.6	1111.8	487.4
Zhejiang	541.6	440.3	26.4	104.5	4978.8	565.6	979.0	418.1
China Total	**20385.3**	**11346.8**	**1048.6**	**3385.0**	**155565.9**	**17440.5**	**38356.0**	**13569.8**

4.3 Emission in scope years

4.3.1 Methodology

This study focuses on the effect of energy policies; therefore, only energy related pollutants are considered. That is, emissions of SO_2, NOx, BC, OC, CO, and NMVOC are assumed to vary in different scope years and scenarios, while emission levels of CH_4 and NH_3 remain steady.

Emissions in future years are calculated by the same equation as (1). The changes of parameters lead to variation of total emission of pollutants. Changes of activity rate represent the change of basic energy demand from economic sectors. They can be derived from the results of LEAP model.

Unabated emission factors and removal efficiency of abatement technologies are assumed to be unaltered during the future years, while the application rate of the abatement technologies changes. This changing represents the effect of the policies, especially pollutants control policies. The details of the policies as well as the indicators of the changes initiated by the policies are listed in Table 3-4.

4.3.2 Activity data

Energy consumption results from the LEAP model are used to generate activity data for emission estimation. As shown in Table 4-1, energy consumption is divided into 5 sectors (industry, domestic, transportation, power, and biomass burning), and the emissions from the 5 sectors are calculated individually. Since the 5 sectors here are not the same as the sectors that were set in the LEAP model, the results from the LEAP model are mapped into our input data for emission inventory as Figure 4-3.

Industry is a demand sector which needs energy supply from upstream sectors. Coal, oil, and electricity are the major energy types consumed in industry. Industry boilers and engines are the major devices combusting coal and oil. The LEAP model generates the energy consumption of industry by fuel type directly, and coal and oil consumption are used as the activities of industry. Electricity is not considered here because its related devices do not emit pollutants directly.

Similar to industry, the domestic sector takes coal and bio-fuel consumption from LEAP model. It is assumed that heat for public buildings comes from heating boilers, which is similar to the residential sector in LEAP. Thus, coal used in the public building sector and the residential sector is summed up as the consumption of coal in the domestic sector for emission calculation. Bio-fuel consumption is taken directly from LEAP model.

Little energy is used in the transportation sector except for oil. Therefore, the oil consumption from the LEAP model is used to calculate the emissions from the transportation sector.

Unlike the previous sectors, the power sector is not an energy demand sector but an energy transformation sector. The power sector transforms several types of primary fuel, such as coal, oil, nature gas, nuclear, hydro, and wind, into electricity and heat. In our emission estimation, activity data in the power sector comes from the results of the LEAP model, which provides inputs of coal, oil, and gas needed to fuel the electricity and heat supply.

Biomass burning is considered, as open burning occurs in forest, grassland, and other areas. Since biomass burning is not relevant to energy consumption, biomass burning is kept as a constant in all scope years.

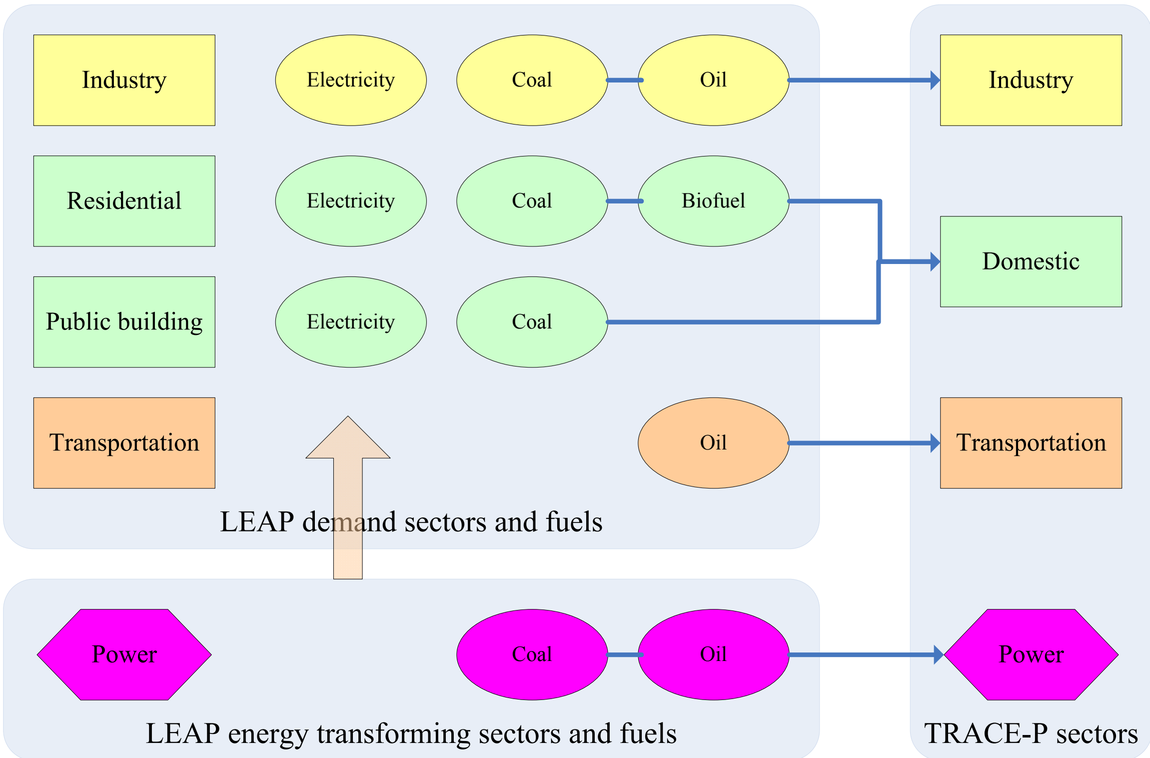


Figure 4-3 Activities from LEAP results

4.3.3 Emission factors

As shown in equation 1, emission factors are determined by unabated emission factors and the effect of emission control technologies. In our emission estimation, it is assumed that the unabated emission factor for each individual technology/fuel does not change in the future years. Thus, the change of emission factors in each scenario reflects the effect of emission control policies and technologies.

Power is the sector which most often demonstrates significant variation between different scenarios. Since power plants consume the largest share of coal in China and emit more than half of the SO_2 emissions, desulfurization of power plants will be implemented widely in the future years. Control of NOx emissions in power plants will also be an important topic. In our estimation of emissions, it is assumed that Flue Gas Desulfurization (FGD) is the dominant technology used to abate SO_2 emission, whose efficiency of desulfurization is 90%. Selective Catalytic Reduction (SCR) is considered the most effective technology available to reduce NOx emissions with an efficiency of 60%.

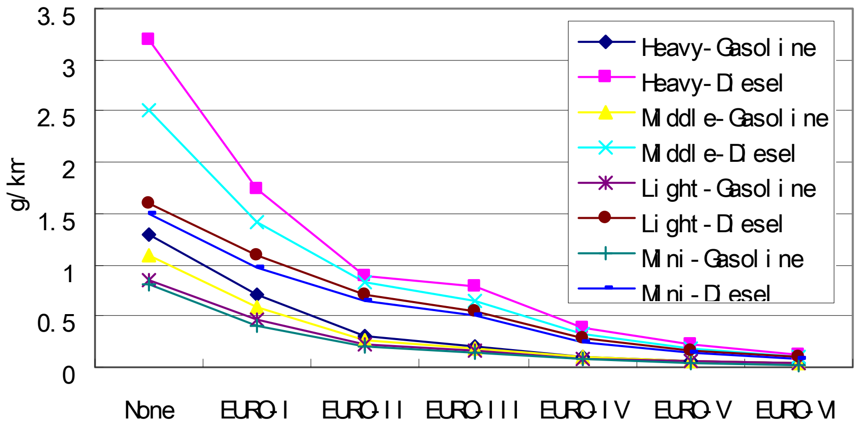


Figure 4-4 Emission factors of NOx for vehicles

On-road transportation is another sector whose emissions are significantly affected by emission control policies. With increasingly strengthened emission standards for on-road emissions, the emission factors for NOx, VOC, CO, and PM will be reduced, as shown in Figure 4-4. A dynamic methodology is used to estimate the average emission factors of on-road vehicles in each year: assuming each vehicle has a life time of 15 years, the share of control technologies for vehicles (e.g., EURO-I , EURO-II, etc.) is derived from the modal mixture of new vehicles in each year *(He K, 2005)* and the year when a new emission standard begins to be implemented. Then, the average emission factors in each individual year are calculated by multiplying the share of control technologies for vehicles by the emission factors of each control technology.

4.3.4 Emission trends

Table 4-8 shows the pollutant emission scenario results for the four cases for the years 2001, 2010, 2020 and 2030. Similar to table 3-6, two indices are also calculated. The first index compares the emissions in 2010 and 2030 with emissions in 2001 for each scenario, and the second shows the emission differences between the two policy cases and the BAU case in 2010 and 2030.

Table 4-8 Emissions trends in Three Scenarios

Scenario	2001	2005	2010	2020	2030	2010/ 2001	2030/ 2001	Case/BAU 2010	Case/BAU 2030
BAU									
SO_2 (Kt)	20,385	22,498	23,009	25,213	28,085	1.13	1.38	1	1
NO_x (Kt)	11,347	12,932	13,995	15,435	17,470	1.23	1.54	1	1
BC (Kt)	1,049	1,050	982	825	691	0.94	0.66	1	1
OC (Kt)	3,385	3,207	2,888	2,201	1,582	0.85	0.47	1	1
CO (Kt)	155,566	161,341	156,835	137,134	128,829	1.01	0.83	1	1
NMVOC (Kt)	17,441	18,832	18,879	17,245	16,945	1.08	0.97	1	1
CO_2 (Mt-C)	878	1,028	1,179	1,468	1,889	1.34	2.15	1	1
Scenario 1	**2001**	**2005**	**2010**	**2020**	**2030**	**2010/ 2001**	**2030/ 2001**	**Case/BAU 2010**	**Case/BAU 2030**
SO_2 (Kt)	20,385	21,951	21,598	22,261	23,382	1.06	1.15	0.94	0.88
NO_x (Kt)	11,347	12,707	13,376	13,999	15,094	1.18	1.33	0.96	0.91
BC (Kt)	1,049	1,002	864	652	514	0.82	0.49	0.88	0.79
OC (Kt)	3,385	3,058	2,565	1,783	1,301	0.76	0.38	0.89	0.81
CO (Kt)	155,566	158,057	149,345	125,668	117,027	0.96	0.75	0.95	0.92
NMVOC (Kt)	17,441	18,525	18,103	15,856	15,198	1.04	0.87	0.96	0.92
CO_2 (Mt-C)	878	991	1,094	1,274	1,560	1.25	1.78	0.93	0.87
Scenario 2	**2001**	**2005**	**2010**	**2020**	**2030**	**2010/ 2001**	**2030/ 2001**	**Case/BAU 2010**	**Case/BAU 2030**
SO_2 (Kt)	20,385	21,733	21,014	18,488	16,067	1.03	0.79	0.91	0.73
NO_x (Kt)	11,347	12,623	13,000	12,406	12,596	1.15	1.11	0.93	0.80
BC (Kt)	1,049	978	817	549	424	0.78	0.40	0.83	0.67
OC (Kt)	3,385	3,017	2,482	1,542	1,166	0.73	0.34	0.86	0.70
CO (Kt)	155,566	156,397	144,813	115,423	111,683	0.93	0.72	0.92	0.84
NMVOC (Kt)	17,441	18,203	17,141	13,610	12,512	0.98	0.72	0.91	0.79
CO_2 (Mt-C)	878	989	1,086	1,259	1,523	1.24	1.73	0.92	0.86

Reflecting the trends of energy demand, the emissions of SO_2, NOx, and CO_2 will increase continuously from 2001 to 2030 in BAU scenario. The emissions of BC and OC, generated mostly from incomplete burning of domestic biomass, will keep decreasing. Emission of CO comes from both fossil fuel and biomass. Due to the combined effects of increasing fuel consumption and decreasing use of low efficiency boilers/stoves on CO, it will increase at first but decline after 2005. In Scenario 1 and 2, emissions are controlled more or less by measures for energy consumption reduction (CCP policies) and pollution control (PCP policies). The emissions trends of CO_2 as well as local pollutants in the two policy scenarios and the BAU scenario are illustrated from Figure 4-5 to 4-11.

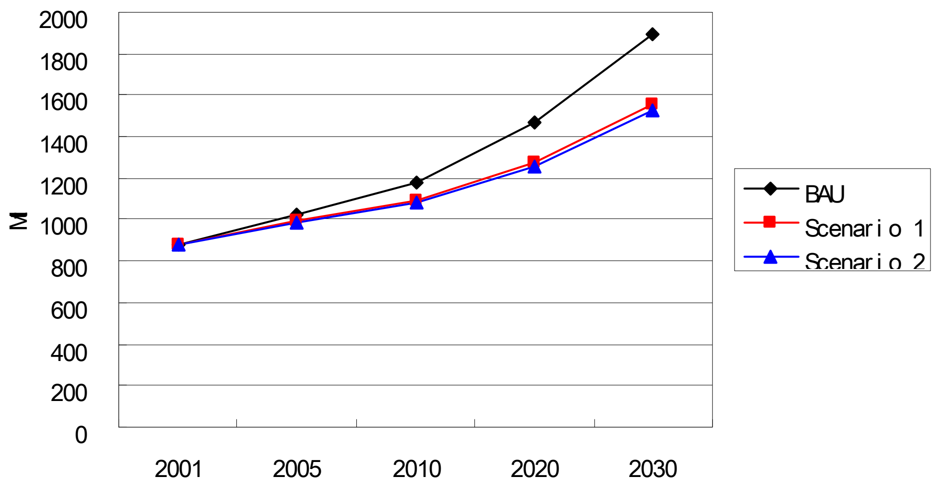


Figure 4-5 Emission trends of CO_2

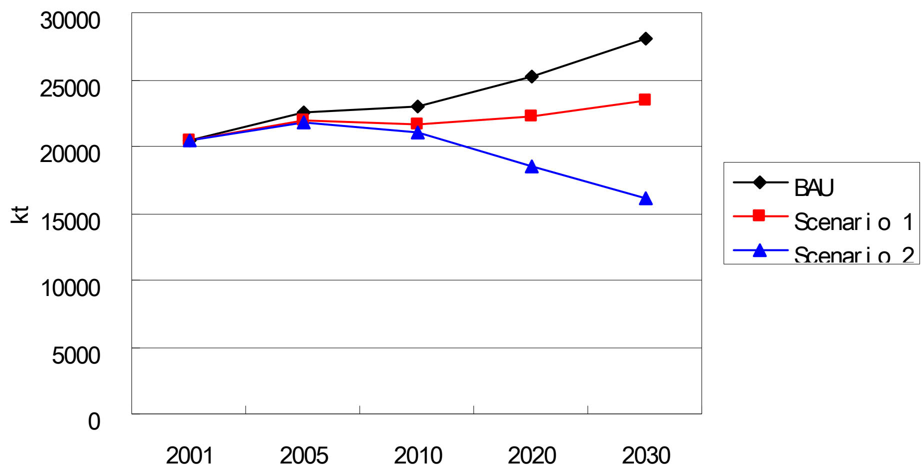


Figure 4-6 Emission trends of SO_2

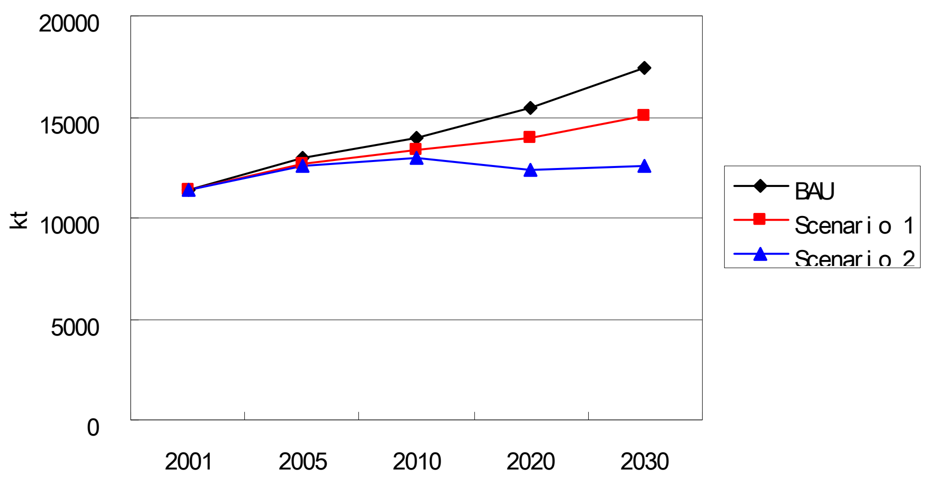


Figure 4-7 Emission trends of NOx

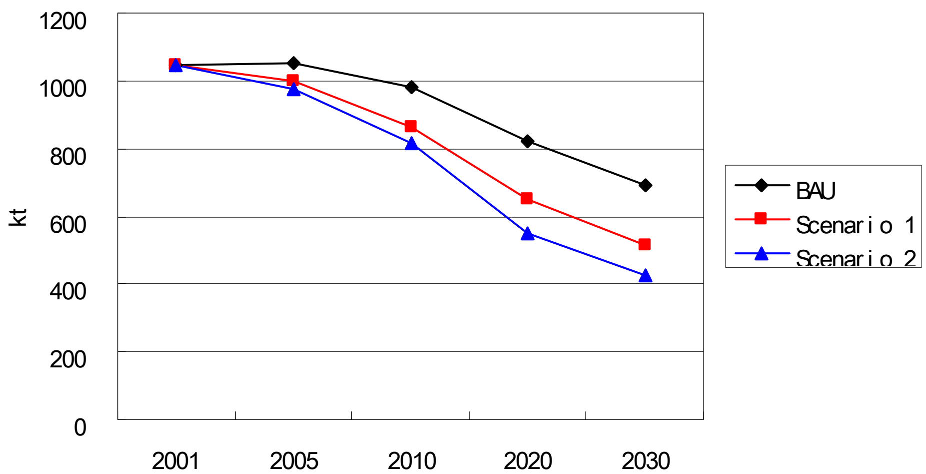


Figure 4-8 Emission trends of BC

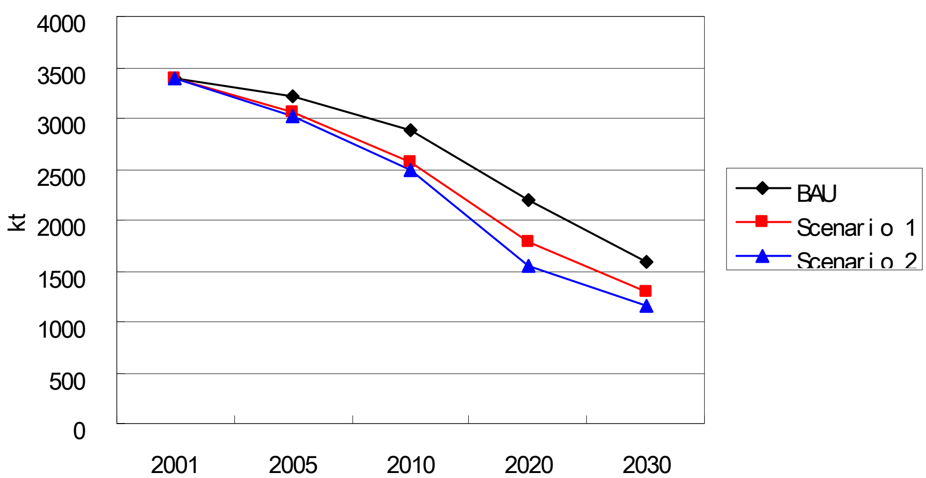


Figure 4-9 Emission trends of OC

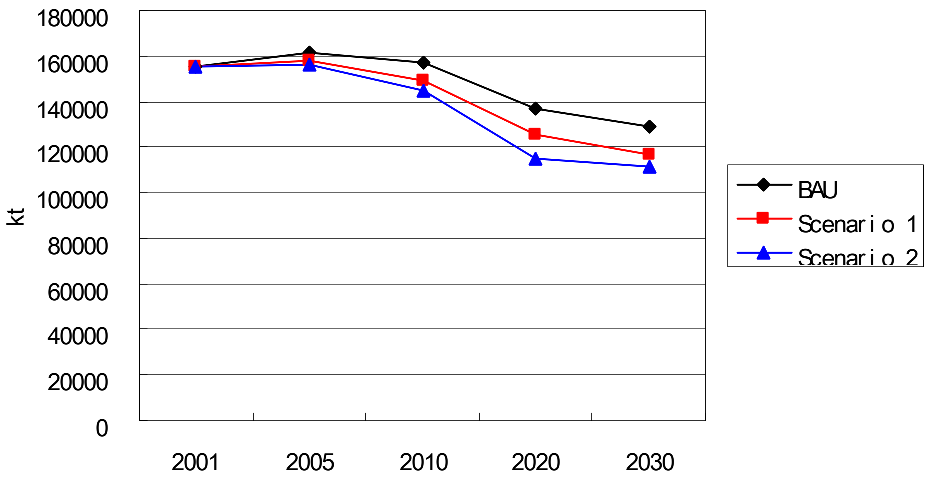


Figure 4-10 Emission trends of CO

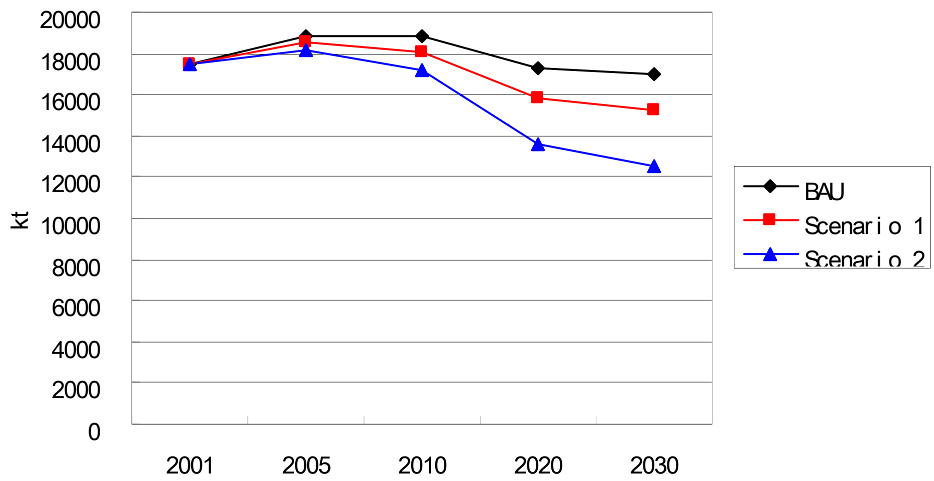


Figure 4-11 Emission trends of NMVOC

In the BAU scenario, emissions of CO_2 in 2030 are 2.15 times that in 2001 (Figure 4-5). This ratio is larger than 2.01, the ratio of total energy consumption in 2030 to 2001. This phenomenon is caused by the reduction in biomass fuel use in the rural residential sector. For a whole life cycle, biomass fuel does not produce CO_2 because it absorbs CO_2 from the atmosphere to grow. Therefore, fuel switching from biomass fuel to fossil fuel in the residential sector increases CO_2 emissions, even though energy consumption falls due to the higher energy efficiency of fossil fuel.

Emission of CO_2 in Scenario 1 is 17% less than BAU, demonstrating the significant CO_2 abatement capability of CCP policies. However, there is little difference between Scenario 1 and Scenario 2. This is because PCP policies are focused on local pollution control, and few of them contribute to CO_2 abatement. Some of them, e.g. FGD and ESP, even lead to more CO_2 emission because the operation of these control measures requires energy. Consequently, PCP policies bring few benefits in addition to those achieved in Scenario 1 in terms of CO_2 reduction.

In the BAU scenario, emissions of SO_2 increase by 38% over 30 years (Figure 4-6). Although the policies for "Two Control Zone" require that new power plants install FGD, rapidly increasing coal consumption leads to a persistent rise in SO_2 emission. CCP policies and PCP policies will result in SO_2 emission reductions of 17% and 25%, respectively. The effect of CCP policies mainly results from reduced energy consumption, and the effect of PCP policies results from the increased application of control technologies, such as more FGD installation in power plants.

The emission trend for NOx is somewhat similar to SO_2 (Figure 4-7). Because of severe pollution from coal combustion in the 1990s, the government paid more attention to SO_2 control. Because concern about NOx in boilers began about 10 years later than concern about SO_2, NOx emission will increase more rapidly than SO_2. Even in Scenario 2, NOx emission in 2030 will be higher than in 2001. If all measures in Scenario 2 are implemented, the ratio of NOx/SO_2 will increase from 0.557 to 0.784 in the next 30 years. This result indicates that NOx will play a more important role in China's acid rain problem. The government should pay more attention to controlling NOx emission in future years.

Emissions trends of BC (Figure 4-8) and OC (Figure 4-9) represent emissions of energy-related PM. The most important source of BC and OC is the residential sector, and biomass fuel takes the most responsibility. With modernization. more commercial energy will replace of biomass fuel in rural China. This will lead to a significant decline in BC and OC emission.

NMVOC (Figure 4-10) and CO (Figure 4-11) result from incomplete burning. NMVOC plays a very important role in atmospheric chemistry reactions, and CO is a relatively good indicator for validating the emission assumptions because it is relatively stable in the atmosphere. For this reason, their emissions trends are also addressed in our inventory although their effect on public health is not considered in this study. The emissions trends of NMVOC and CO are similar. With increasing energy consumption, their emissions will rise in the early 2000s. After 2010, the implementation of stricter vehicle standards and the switch from low energy efficiency biomass stoves to coal and gas stoves will reduce emissions of NMVOC.

To compare the benefits of policies on local emissions reductions, the ratio of emissions in Scenarios 1 and 2 to BAU is calculated. In 2030, emissions in Scenario 1 are 74% ~ 91% of BAU, and emissions in Scenario 2 are 57% ~ 87% of BAU. The results indicate that not only PCP policies, but also CCP policies have significant potential to reduce local and regional air pollutants.

Of the measures evaluated here, the CCP policies are the best choice if it is desirable to reduce emissions of GHG and local/regional pollutants at the same time. PCP policies are efficient to control local/ regional pollutants, but they offer few benefits in terms of GHG abatement.

4.3.5 Impact on sector emissions

The emission trends for scenarios are presented in Figures 4-12 to 4-17 at the sector level. Each figure shows the base emissions in 2001 and emissions in scope years for the 3 scenarios.

Figure 4-12 shows the trends of SO_2 emissions. Industry and power are the major sources. Emissions from the power sector are relatively stable in the BAU scenario, but power sector emissions drop significantly after 2010 in Scenario 2. This shows that the conversion of old units to new ones with FGD is effective in eliminating SO_2. The difference in emissions from the industry sector is not as distinct as the difference in the power sector in the 3 scenarios. This is because the control technologies for industry boilers are less effective than for power plant boilers, and the distribution of such technologies is more difficult in the industry sector than in the power sector. Coal consumption is the major source of SO_2 in the residential sector. Fuel switching in the residential sector reduces SO_2 emission in Scenarios 1 and 2.

Similar to the situation for SO_2 emissions, the power and industrial sectors remain dominant in NOx emission in all scenarios (Figure 4-13). With the progress of SO_2 control in China, especially in the “Two Control Zone”, control of NOx is of more and more concern to policy makers. Research of denitrogenate technologies will take place in the “Eleventh Five-Year Plan”. Installation of SCR devices in power plants will be effective beginning in 2020, but the power sector is always the most important source of NOx. The transportation sector is another important source of NOx. New vehicles under the EURO series standard have fewer emissions than old ones, but emission from the transport sector will not decrease until 2010 because of the continuously increasing vehicle population and the maintenance of old vehicles for a long time.

Most BC (Figure 4-14) and OC (Figure 4-15) emissions result from the residential sector and biomass open burning. Fuel switching in the residential sector is quite effective in reducing BC and OC emissions. Although it is estimated that the emissions of BC and OC from biomass open burning will remain at their 2001 levels, emissions will be lower if the government implements effective measures forbidding the rural burning of crop residuals.

The sources of CO emissions (Figure 4-16) are a little more complex. Industry, transport, domestic and biomass burning represent the majority of CO emissions. According to the results, emissions from the residential sector decline significantly, especially from biofuel consumption. CO emissions are also reduced by fuel switching in rural China. Emissions from transport decrease due to the implementation of new vehicle standards. Industry and biomass burning emissions remain relatively stable.

Although total NMVOC emissions (Figure 4-17) in the BAU do not change a lot, emissions from the industry sector increase while emissions from the transport sector decrease. Vehicle standards help reduce NMVOC emissions, and PCP policies have a remarkable effect on controlling emissions from industry, especially, in the long term.

4.3.6 CO_2 emissions from different fuels

Coal is the dominant energy resource in China, and thus CO_2 from coal burning is the most important emissions source, as shown in Figure 4-18. With societal modernization and China's increasing oil and nature gas consumption, CO_2 emissions and the proportion of CO_2 from oil products and nature gas will obviously increase. Energy consumption in Scenarios 1 and 2 is less than in BAU, but nearly all of the difference lies in reductions in coal consumption. In each scope year, the policies have little effect on CO_2 emission from oil and gas.

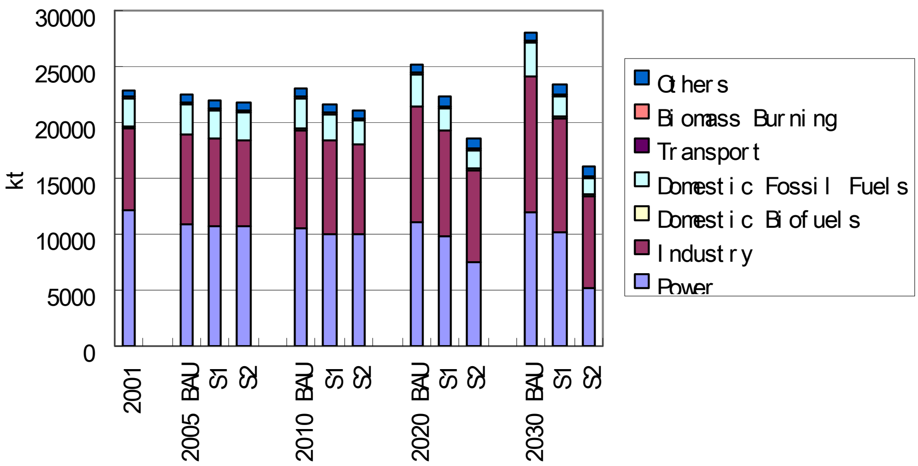


Figure 4-12 SO_2 emission by sectors

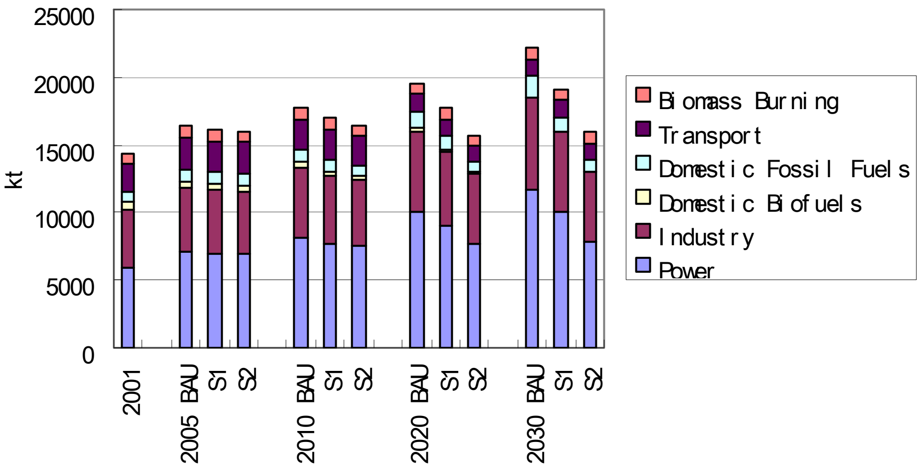


Figure 4-13 NOx emission by sectors

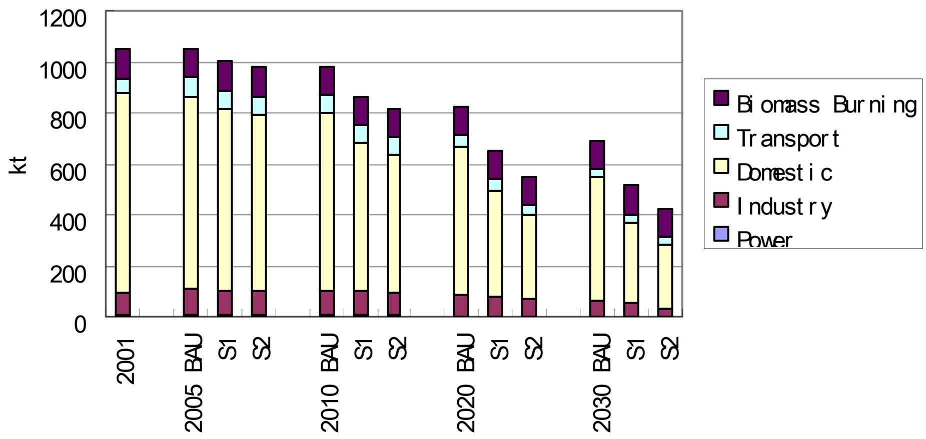


Figure 4-14 BC emission by sectors

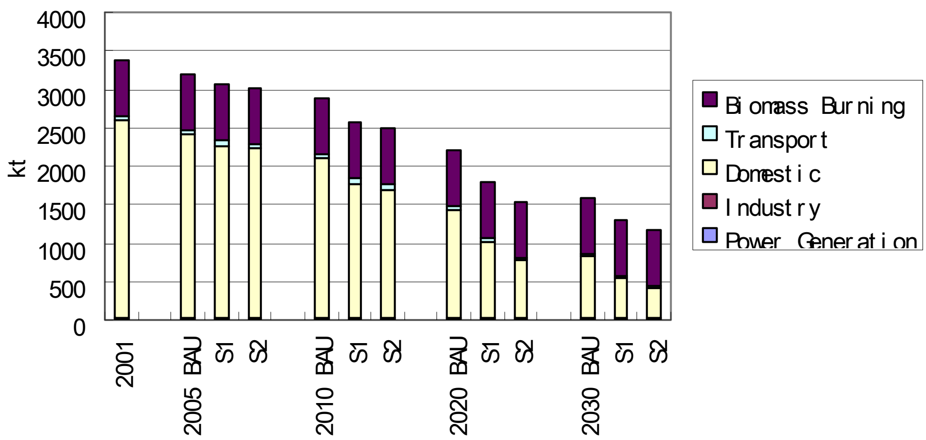


Figure 4-15 OC emission by sectors

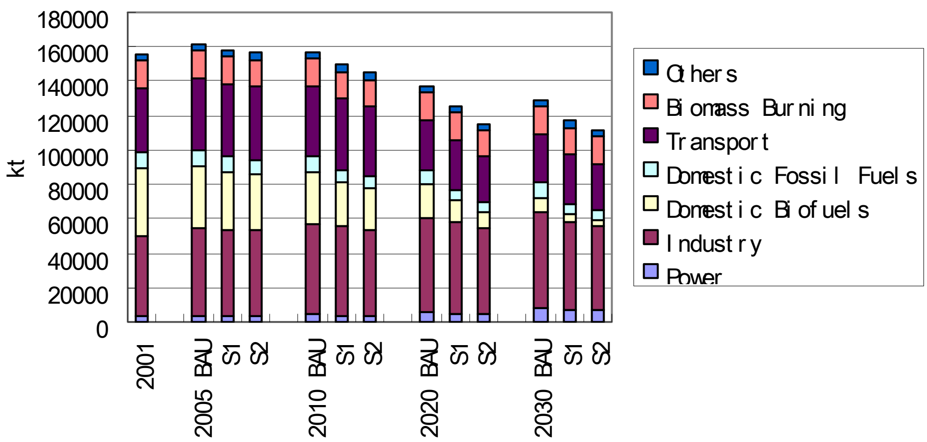


Figure 4-16 CO emission by sectors

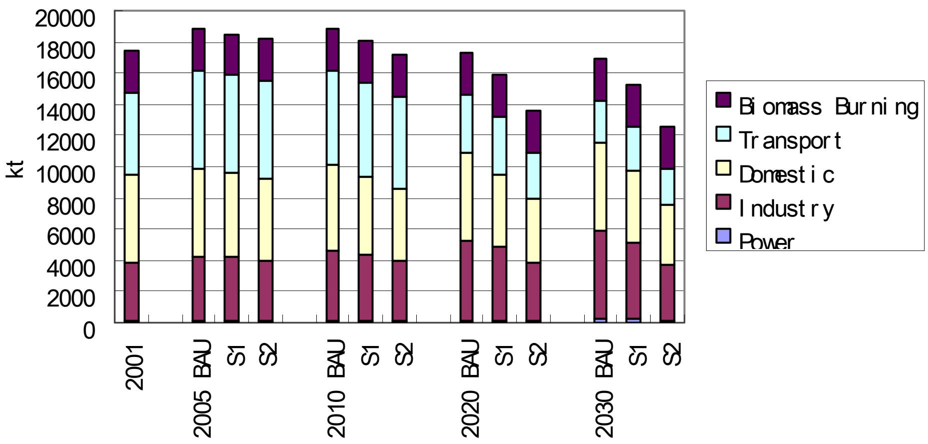


Figure 4-17 NMVOC emission by sectors

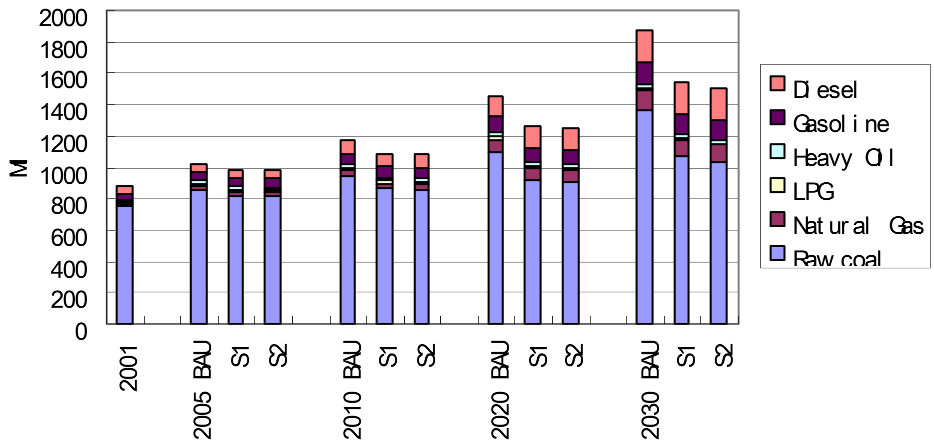


Figure 4-18 CO_2 emission by fuels

CHAPTER 5 Simulation of national air quality

5.1 Methodology and data

This research adopted Models-3 (CMAQ), which is recommended by U.S. EPA to simulate the air quality in city areas (EPA, 1996).

5.1.1 Introduction

To meet both the challenges posed by the CAAA-90 and the need to address the complex relationships between pollutants, the U.S. EPA embarked upon the Models-3 project and developed the Community Multiscale Air Quality (CMAQ) system, an advanced air quality modeling system that addresses air quality from the “one atmosphere” multi-pollutant perspective (figure 5-1). Based on its conceptual design, the high performance computational Models-3 framework serves to manage and orchestrate air quality simulations, using the CMAQ modeling system. The Models-3 framework is an advanced computational platform that provides a sophisticated and powerful modeling environment for science and regulatory communities. The framework provides tools used to develop and analyze emission control options, integrate related science components into a state-of-the-art quality modeling system, and apply graphical and analytical tools for facilitating model applications and evaluation.

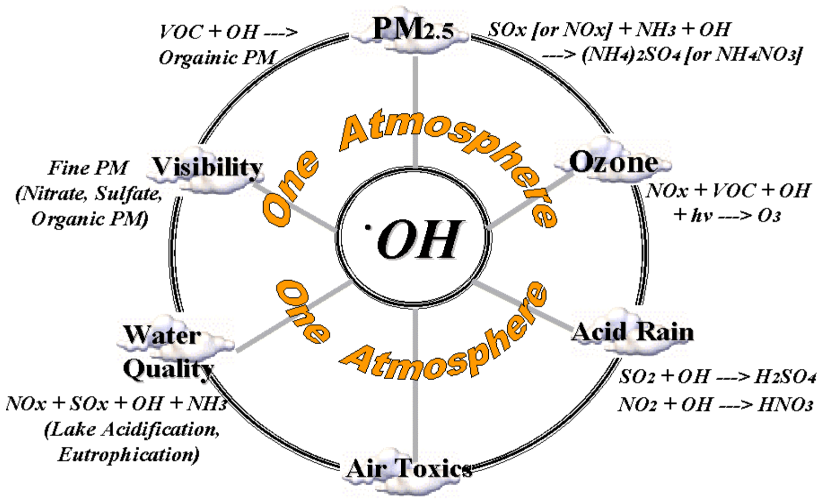


Figure5-1 One Atmosphere – the relationship between pollutants

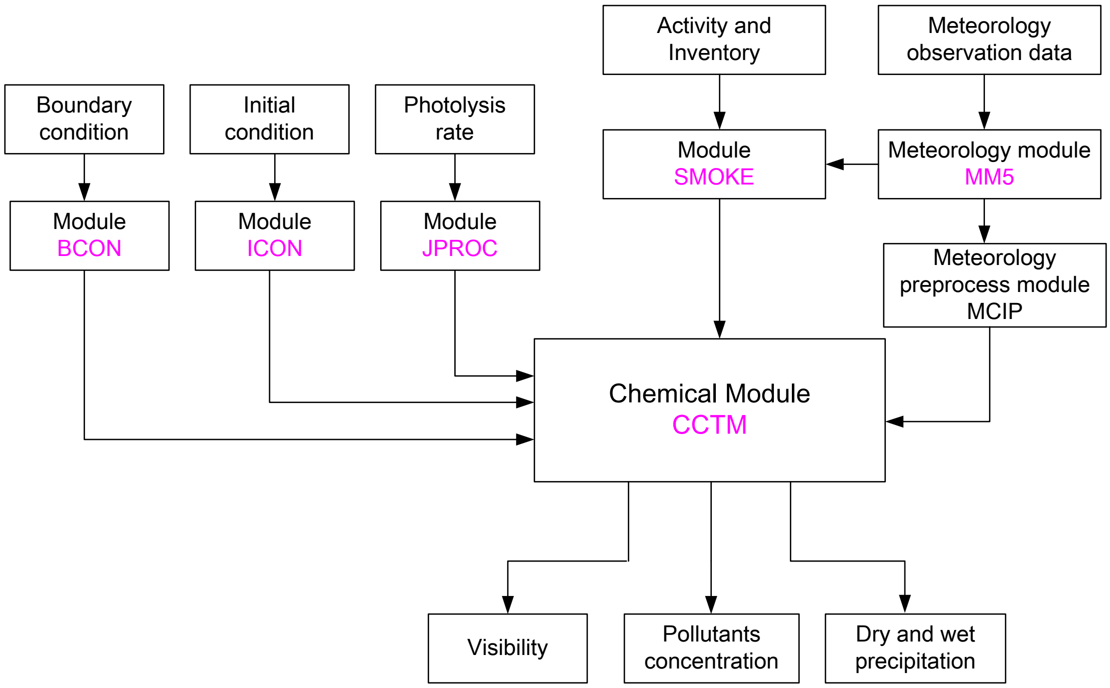


Figure 5-2 Models3/CMAQ structure and core modules

The structure of the Models-3/CMAQ system is shown in Figure 5-2. Orchestrated through the Models-3 system framework, the Community Multi-scale Air Quality (CMAQ) modeling system incorporates output fields from emissions and meteorological modeling systems and several other data sources through special interface processors into the CMAQ Chemical Transport Model (CCTM). CCTM then performs chemical transport modeling for multiple pollutants on multiple scales. With this structure, CMAQ retains flexibility to substitute other emissions processing systems and meteorological models. One of the main objectives of this project was to provide an air quality modeling system with a "one atmosphere" modeling capability based mainly on the "first principles" description of the atmospheric system. CMAQ contains state-of-science parameterizations of atmospheric processes affecting transport, transformation, and deposition of such pollutants as ozone, particulate matter, airborne toxics, and acidic and nutrient pollutant species. With science in a continuing state of advancement and review, the modeling structure of CMAQ is designed to integrate and to test future formulations in an efficient manner, without requiring the development of a completely new modeling system.

Each of these three modeling systems is described briefly below.

The Emission-Chemistry Interface Processor (ECIP) translates data from the MEPPS emission model for use in the CCTM. ECIP generates hourly three-dimensional emission data for CMAQ from the separate source type files produced by MEPPS, which include mobile, area, and point sources. ECIP calculates the plume rise and initial vertical plume spread of point source emissions to determine the vertical level(s) of CCTM into which point source emissions should be introduced. Since meteorological conditions affect both point source plume rise and biogenic emissions, meteorological data from MCIP is also used in ECIP.

The Meteorology-Chemistry Interface Processor (MCIP) translates and processes model outputs from the meteorology model for the CCTM. MCIP interpolates the meteorological data if needed, converts between coordinate systems, computes cloud parameters, and computes surface and planetary boundary layer (PBL) parameters for the CCTM. MCIP uses landuse information from the landuse processor (LUPROC) to calculate the PBL and surface parameters.

Initial Conditions and Boundary Conditions (ICON and BCON) provide concentration fields for individual chemical species for the beginning of a simulation and for the grids surrounding the modeling domain, respectively. The ICON and BCON processors use data provided from previous three-dimensional model simulations or from clean-troposphere vertical profiles. Both the vertical profiles and modeled concentration fields have specific chemical mechanisms associated with them, which are functions of how these files were originally generated.

The photolysis processor (JPROC) calculates temporally varying photolysis rates. JPROC requires vertical ozone profiles, temperature profiles, a profile of the aerosol number density, and the earth's surface albedo to produce the photolysis rates for the CCTM. JPROC uses this information in radiative transfer models to calculate the actinic flux needed for calculating photolysis rates. JPROC generates a lookup table of photo-dissociation reaction rates.

Each of these CMAQ interface processors incorporates raw data into CMAQ and performs functions such as calculating parameters and interpolating or converting data. Raw input data is currently specified in the source code for JPROC, LUPROC, ICON, and BCON. However, the interface processors in future releases of CMAQ will be modified to handle a more generalized set of raw input data, so that alternative data sets with varying resolutions or measurement units can be used.

The CMAQ Chemical Transport Model (CCTM) simulates the relevant and major atmospheric chemistry, transport and deposition processes involved throughout the modeling domains. The science options available to the user include the gas phase chemistry mechanisms, RADM2 and CB-IV, a set of numerical solvers for the mechanisms, options for horizontal and vertical advection schemes, algorithms for fine and coarse particulate matter predictions, photolysis rates, and a plume-in-grid approach.

5.1.2 Mapping the emission inventory

Using CMAQ to simulate the concentrations of the pollutants requires defining and gridding the target area and providing the geographical information of the emission sources and receptors. Lambert projection was used with the two true latitudes of 25^{o}N and 40^{o}N. The original point was 34^{o}N, 110^{o}E and the coordinates of the bottom left corner of the largest domain were (x=-2934km, y=-1728km). Domain covers most area of East Asia with 36×36km resolution.

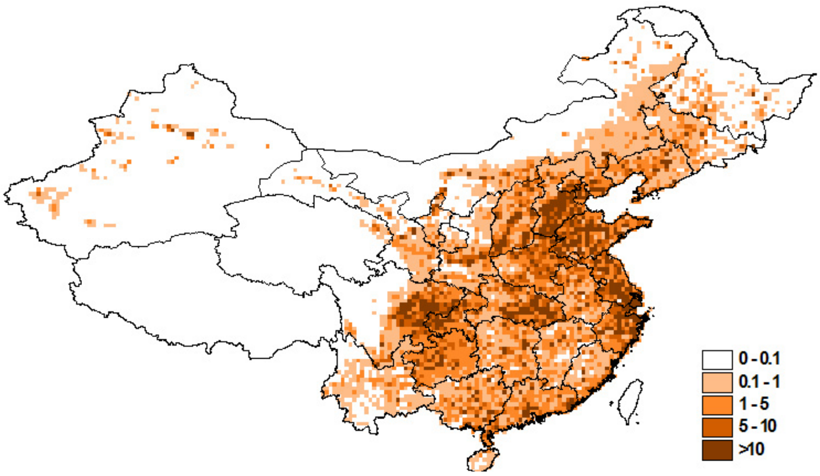
The provincial emission data was spatially allocated to high resolutions (gridding) by GIS information such as landuse, population density, road network, etc. The total emissions were distributed into the grids spatially according to the principles listed in Table 5-1, and the results were expressed using geographical information system

(GIS). Using the Trace P emission inventory, the temporal variation coefficients of the emission sources from the Trace-P emission inventory were estimated to present the variation in emissions with seasons, days and hours. They were then used to calculate the ambient concentration and distribution of the pollutant hourly.

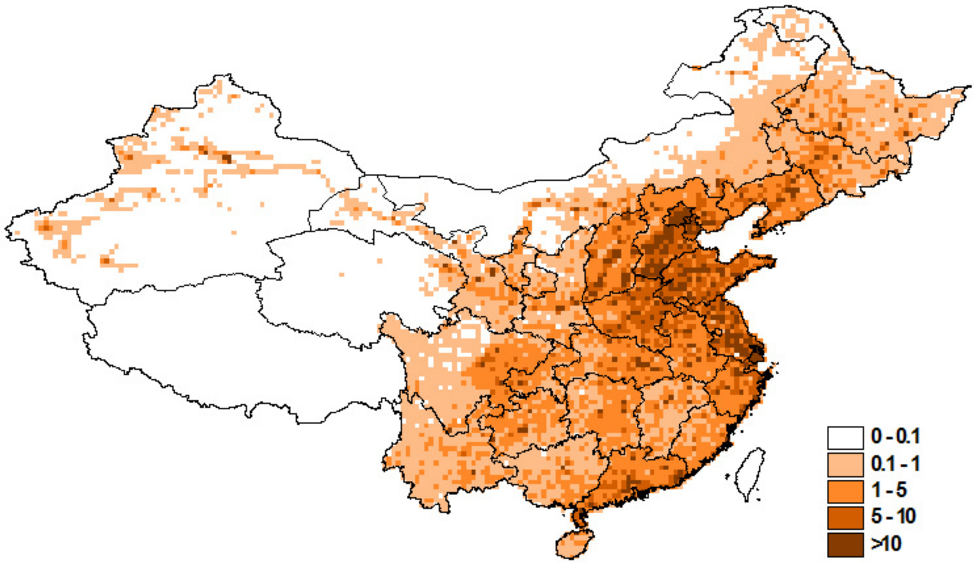
Table 5-1 Principles for spatial distribution of emissions

Type of sources	Principles
Large point sources	Detail location
Vehicles	Distribution of road nets
Household cooking and heating	Population distribution
Fugitive dust	Land use

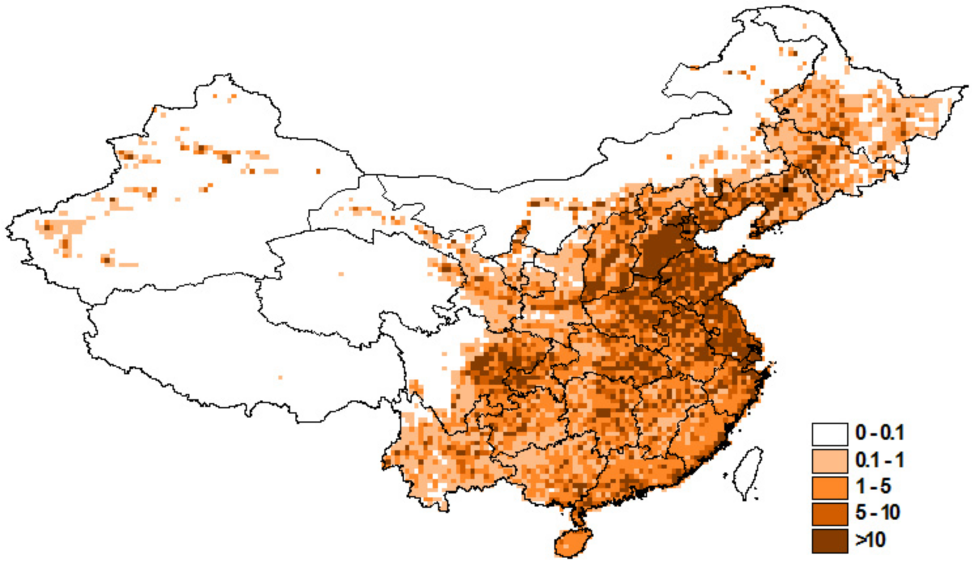
According to the emission inventory, the emission distribution of the pollutants in China in the base year is shown in Figure 5-3. High emissions of SO_2, NO_2 and $PM_{2.5}$ occurred in the middle and east of China, which have rapidly developing economies and show the characteristics of industrial emission and residential emission. For SO_2, high emissions occurred in the southwest areas where high sulfate content coal is burning. For $PM_{2.5}$, middle and eastern China showed high emissions intensity for industrial and residential emission. Southwest China showed especially high emissions intensity due to the widespread use of biofuel in the residential sector.



(a) SO_2



(b) NO_x



(c) Primary PM2.5

Figure 5-3 Emission distribution of pollutants in China in 2001 ($t/km^2 \cdot year$)

5.1.3 Meteorology data

The MM5 model Version 3.7 was applied to generate the meteorological fields. The pressure of top surface was 100mb, and 23 vertical layers were used in modeling. Terrain and landuse data came from the U.S. Geological Survey (USGS) database. European Center for Medium-Range Weather Forecasts (ECMWF)/Tropical Ocean Global Atmosphere (TOGA) analysis datasets were applied to generate the first guess field and National Center of Environmental Prediction (NCEP) Automated Data Processing (ADP) data were utilized in objective analysis.

5.2 Model verification and air quality simulation

5.2.1 Verification of the model

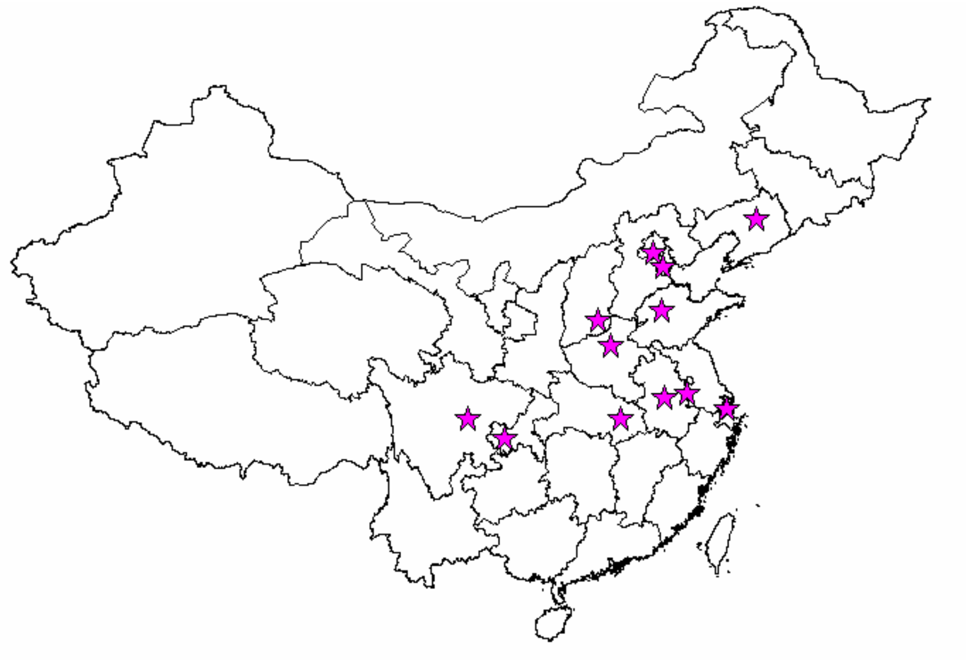


Figure 5-4 Monitoring urban cities for verification

Based on the pollution emission inventory and the meteorology data in China in 2001, CMAQ was used to calculate the annual, monthly, daily and hourly ambient concentrations of SO_2, NOx, and $PM_{2.5}$ at 12 urban cities (in figure 5-4 and table 5-2).

Table 5-2 The location of monitoring sites of urban cities

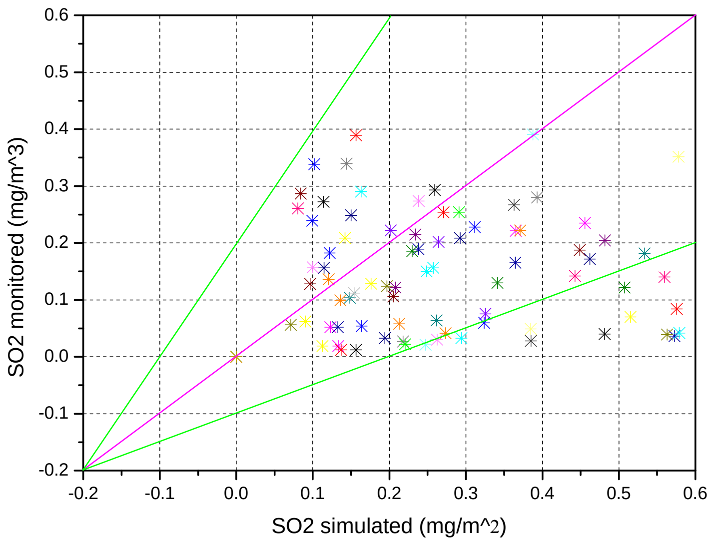
Code	City	Longitude	Latitude	Code	City	Longitude	Latitude
1	Beijing	116.47	39.90	7	Wuhan	114.33	30.62
2	Tianjin	117.17	39.17	8	Hefei	117.27	31.85
3	Shenyang	123.38	41.80	9	Nanjing	118.77	32.05
4	Jinan	117.03	36.67	10	Shanghai	121.43	31.20
5	Shijiazhuang	114.43	36.05	11	Chengdu	104.07	30.65
6	Zhengzhou	113.70	34.73	12	Chongqing	106.55	29.55

The monitoring values taken from the urban city daily API reports for January of 2001, were calculated for verification (figure 5-5). The API of a day is the maximum of the subindexes of pollutants reported, and the pollutant with the highest subindex is cited as the major pollutant. In the air quality report published by the monitoring sites, only the daily API value of the major pollutant can be obtained. The data is limited for SO_2 and NO_2, because they are not the major pollutant most days. For PM, the monitoring values in API reports are given in the form of PM_{10},. No other $PM_{2.5}$ monitoring data can be obtained by any other channel. These are the reasons for the limited monitoring data used here.

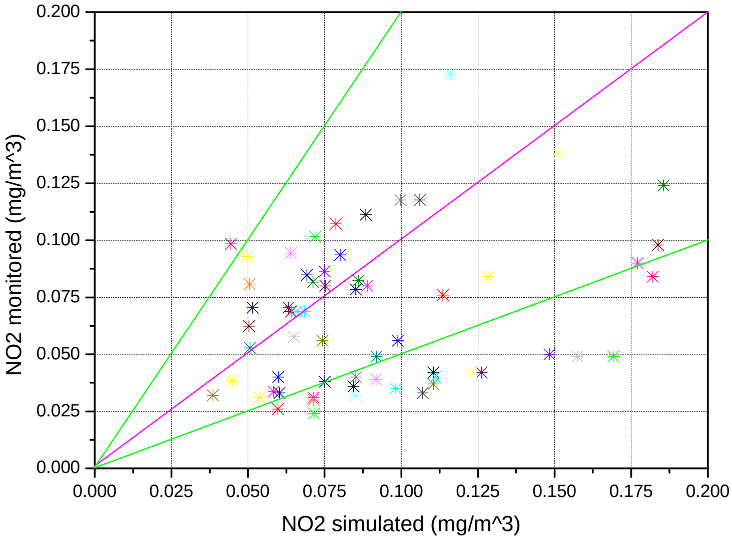
Only Beijing and Shanghi were used for SO_2 and NO_2 comparison purposes because the other cities had limited monitoring data. For $PM_{2.5}$ comparison, the monitoring values in the API reports are given in the form of PM_{10}; additional $PM_{2.5}$ monitoring data can not be obtained by any other channel. The daily simulation results of $PM_{2.5}$ and the monitoring value of PM_{10} were used to conduct the preliminary verification for PM. Figure 5-5 (c) compares the daily simulation results of $PM_{2.5}$ and the monitoring value of PM_{10}. Thus, there is an obvious overestimate of $PM_{2.5}$ in figure 5-5(c), but the $PM_{2.5}/PM_{10}$ ratio is constant and in a reasonable range. Using figure 5-5, it is apparent that most of the comparison error was within ±100%. The simulation results for SO_2 and NO_2 were quite close to measured results.

For the simulation results and the monitoring values by months the simulation results were generally quite close to the monitoring values for all the urban cities with adequate monitoring datum. For example, in January of 2001 in Beijing, the simulated values for SO_2 and NO_2 of 0.23 and 0.07 mg/m^3 were very close to the monitoring values of 0.20 and 0.08 mg/m^3,..

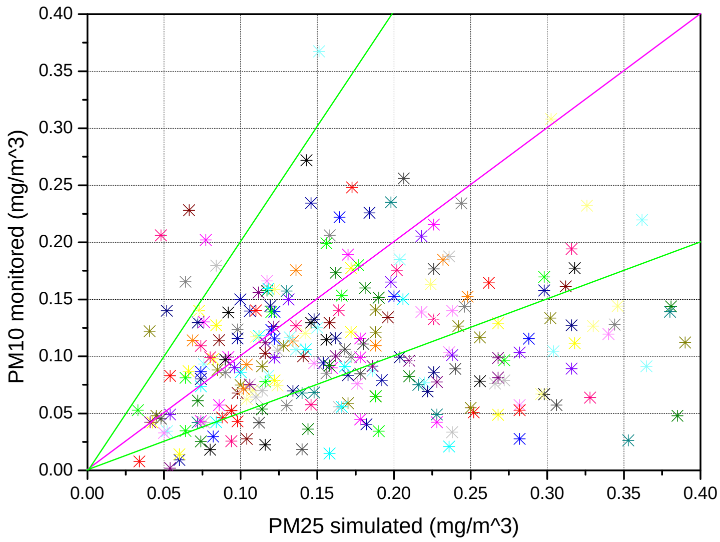
Therefore, it was concluded that the CMAQ model was suitable and feasible to simulate the pollution situation in China.



(a) Daily average concentration of SO_2



(b) Daily average concentration of NOx



(c) Daily average concentration of $PM_{2.5}$

Figure 5-5 Comparison of simulation results and monitored value of daily concentration (Different color stands for different cities)

5.2.2 The air quality in the base year

The distribution of pollutant average concentrations in the target areas are shown in Figures 5-6~8, using the example of January of 2001. The pollution concentration of SO_2, NOx and $PM_{2.5}$ in the target areas revealed the same distribution characteristics as the emissions, with high concentration in middle and eastern China. In addition, for SO_2 and $PM_{2.5}$, the southwest areas showed especially high concentration in addition to high concentrations in middle and eastern China.

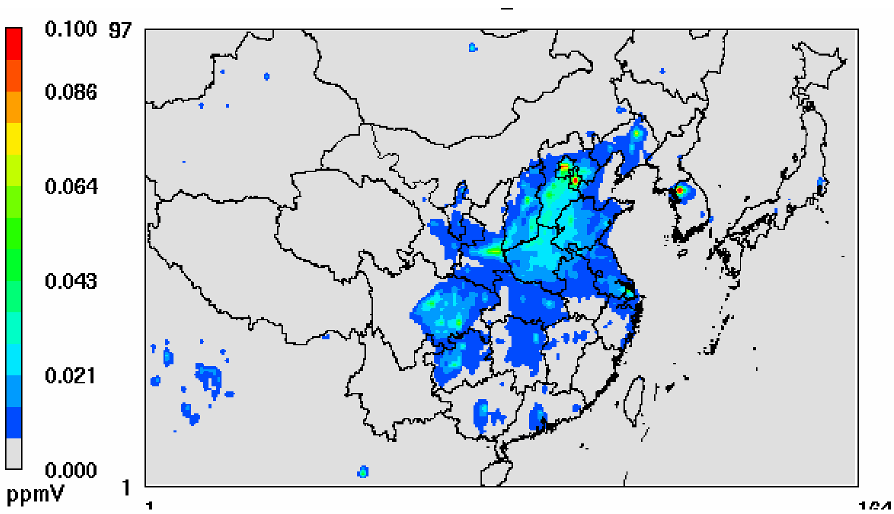


Figure5-6 Average Concentration distribution of SO_2 in Jan 2001 (unit: ppm)

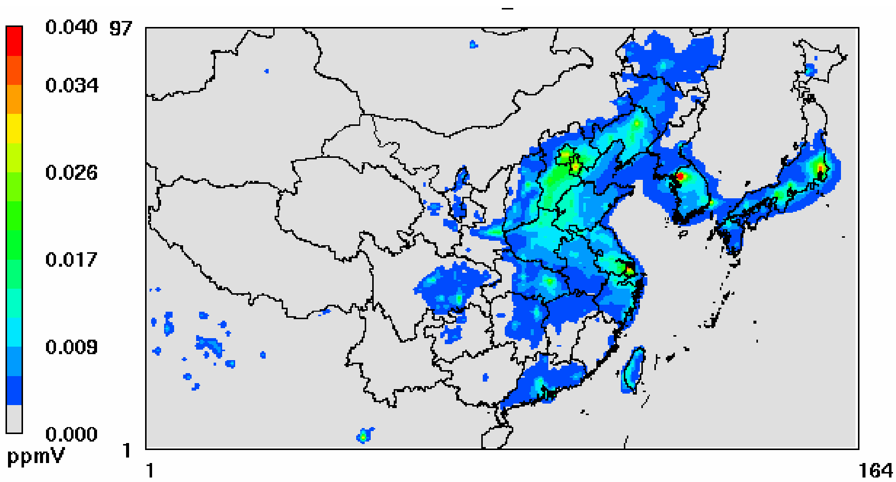


Figure 5-7 Average Concentration distribution of NO_2 in Jan 2001 (unit: ppm)

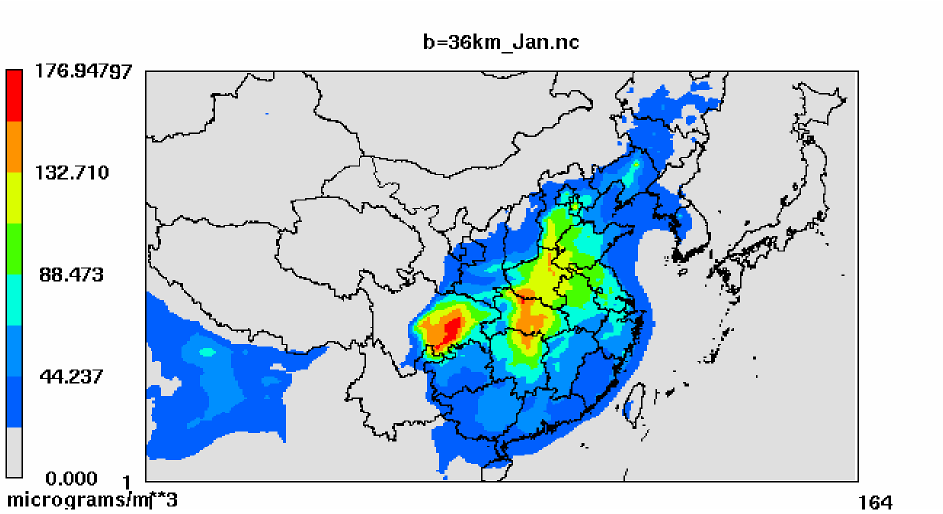


Figure 5-8 Average Concentration distribution of Total $PM_{2.5}$ (Primary + Secondary) in Jan 2001 (unit: ug/m^3)

5.3 Simulation of the Air

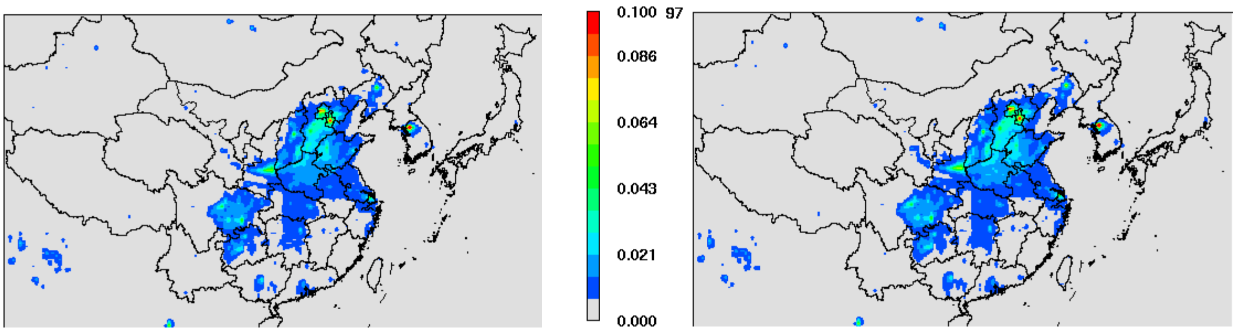
According to the simulation results, the ambient distribution of the pollutants in the target area under different energy scenarios can be acquired, and the effect of each energy consumer on the ambient pollutant concentration can be measured. Comparing the national air quality under different energy scenarios, the energy policy measures proposed above were evaluated.

5.3.1 BAU scenario

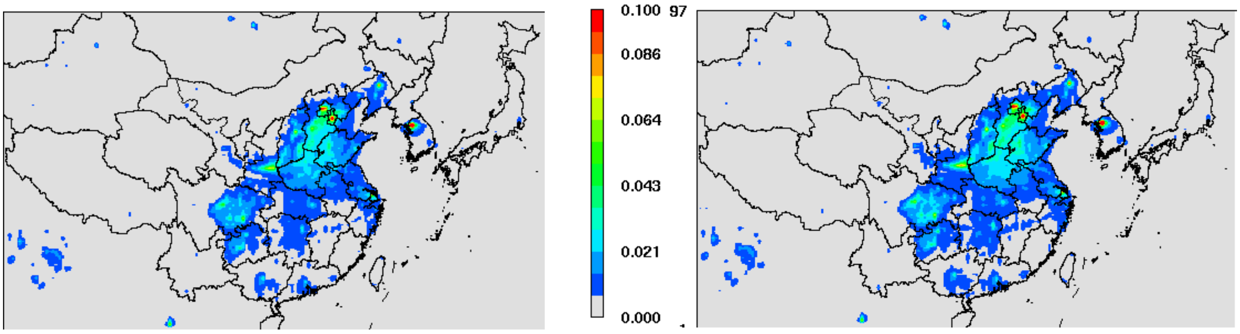
The energy-related ambient concentrations of the pollutants in the target years (2005, 2010, 2020, and 2030) are shown in Figures 5-9~11, using the example of January of 2001. The concentrations trend under the BAU scenarios are shown in Tables 5-3~5.

According to the simulation results, the contribution of energy activities to the concentration of the three pollutants will all increase. The heavily polluted areas in the middle, east and southwest of China will expand. The energy-related S02 concentration will increase most rapidly, from a national average of 4.4ug/m^3 in 2005 to 5.6ug/m^3 in 2030, a 28% increase. For the 12 urban cities, the average value will increase from 64.1 ug/m^3 in 2005 to 82.3ug/m^3 in 2030. The three most heavily polluted areas show the most rapidly increasing ratios; the middle area including Beijing, Tianjin and Senyang, the east Changjiang river delta area including Zhengzhou, Wuhan, Hefei and Nanjing, and the southwest area including Chongqing and Sichuan. The effect of energy activities on SO_2 concentration is shown to be particularly serious in the rapidly developing cities. The areas with high energy-related NO_2 concentrations are distributed in the three high polluted areas, which are quite similar to those of SO_2.

In BAU, the energy-related $PM_{2.5}$ concentration will increase somewhat slowly, BC and OC will slowly decrease, and SO_2 and NO_2 will increase over the next 30 years. BAU causes $PM_{2.5}$ concentration to increase 10% nationally by 2030, from 10.2ug/m^3 in 2005 to 11.3ug/m^3. For the 12 urban cities, annual average $PM_{2.5}$ will increase from 59.8 ug/m^3 to 63.9 ug/m^3. The most rapid increase is predicted for ChengDu of southwest China, with annual average $PM_{2.5}$ increasing from 62.5 ug/m^3 to 70.9 ug/m^3 . The areas with high energy-related $PM_{2.5}$ concentrations are distributed in the three most polluted areas: middle, eastern and southwestern China.

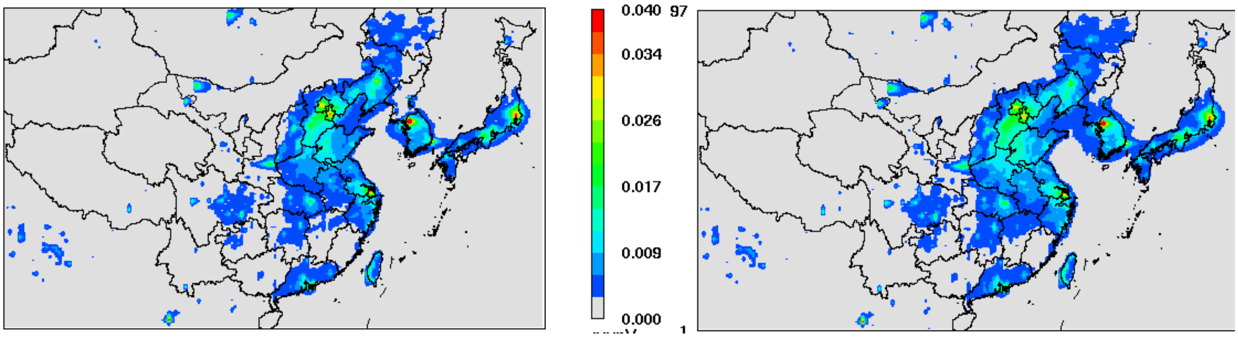


(a) 2005 (b) 2010

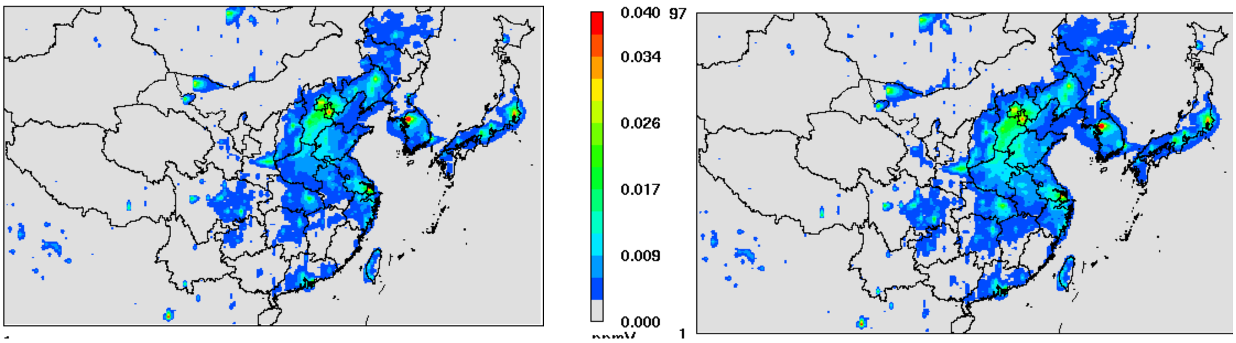


(c) 2020 (d) 2030

Figure 5-9 Average Concentration distribution of SO_2 under the BAU scenario in Jan (unit: ppm)

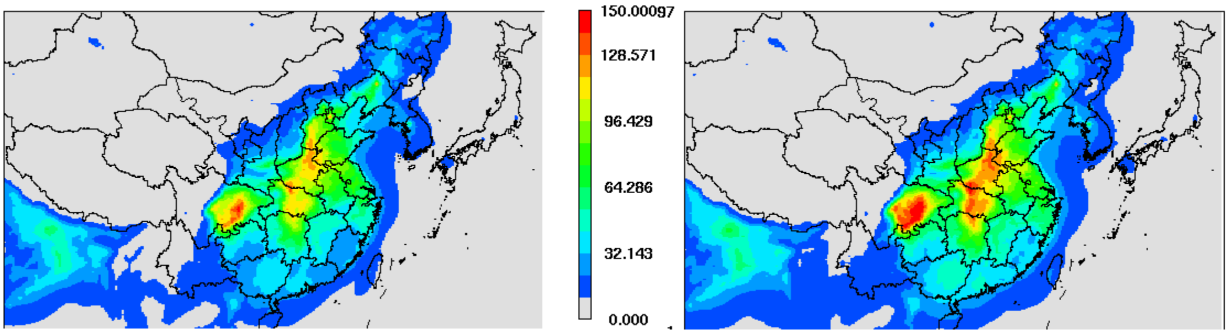


(a) 2005 (b) 2010

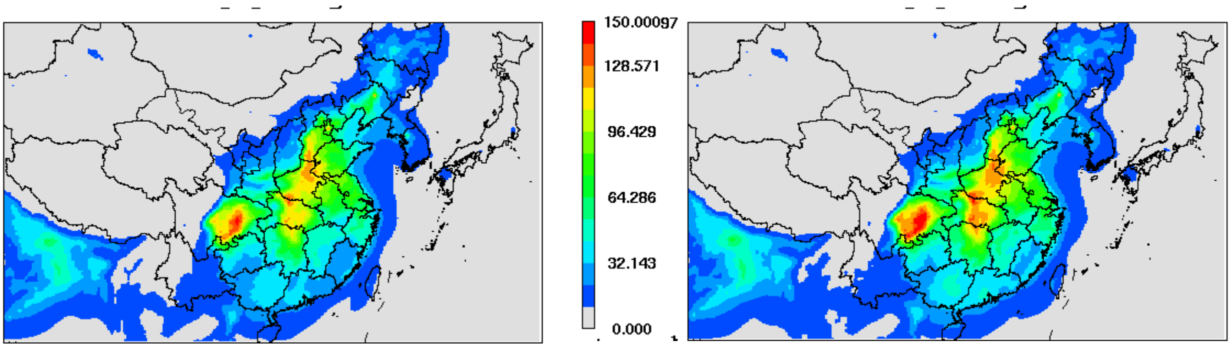


(c) 2020 (d) 2030

Figure 5-10 Average Concentration distribution of NO_2 under the BAU scenario in Jan (unit: ppm)



(a) 2005 (b) 2010



(c) 2020 (d) 2030

Figure 5-11 Average Concentration distribution of Total $PM_{2.5}$ (Primary + Secondary) under the BAU scenario In Jan (unit: ug/m^3)

Table 5-3 Annual average SO_2 concentration trends under the BAU scenario*

	2005		2010		2020		2030	
	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio
National average	4.4	1.00	4.7	1.07	5.0	1.14	5.6	1.28
Beijing	124.0	1.00	131.6	1.06	143.3	1.16	159.5	1.29
Tianjin	112.8	1.00	118.2	1.05	132.7	1.18	147.7	1.31
Shenyang	53.3	1.00	57.3	1.07	65.4	1.23	74.1	1.39
Jinan	86.9	1.00	88.6	1.02	93.8	1.08	99.0	1.14
Shijiazhuang	35.2	1.00	36.9	1.05	41.4	1.18	46.2	1.31
Zhengzhou	33.5	1.00	35.9	1.07	39.6	1.18	44.8	1.34
Wuhan	30.9	1.00	32.2	1.04	36.0	1.17	39.9	1.29
Hefei	20.9	1.00	22.0	1.06	24.5	1.18	27.7	1.32
Nanjing	20.9	1.00	21.9	1.05	24.0	1.15	26.3	1.26
Shanghai	78.1	1.00	82.5	1.06	93.1	1.19	103.5	1.32
Chengdu	60.6	1.00	65.0	1.07	72.5	1.20	81.9	1.35
Chongqing	112.5	1.00	114.8	1.02	127.1	1.13	136.6	1.21
Urban average	64.1	1.00	67.2	1.05	74.4	1.16	82.3	1.28

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year 2005.

Table 5-4 Annual average NO_2 concentration trends under the BAU scenario*

	2005		2010		2020		2030	
	Concentration (μg/m3)	Ratio	Concentration (μg/m3)	Ratio	Concentration (μg/m3)	Ratio	Concentration (μg/m3)	Ratio
National average	2.3	1.00	2.6	1.12	2.2	0.97	2.5	1.11
Beijing	42.0	1.00	41.1	0.98	40.9	0.97	42.6	1.01
Tianjin	44.8	1.00	44.1	0.98	42.5	0.95	44.4	0.99
Shenyang	25.0	1.00	24.6	0.98	25.5	1.02	26.6	1.07
Jinan	24.9	1.00	26.0	1.04	23.3	0.94	24.7	0.99
Shijiazhuang	10.9	1.00	13.6	1.24	11.2	1.02	14.1	1.29
Zhengzhou	9.8	1.00	12.0	1.23	10.7	1.10	13.6	1.39
Wuhan	17.9	1.00	19.8	1.11	19.7	1.10	22.4	1.25
Hefei	10.0	1.00	11.7	1.17	11.1	1.11	13.3	1.33
Nanjing	11.1	1.00	12.5	1.13	10.9	0.98	12.4	1.12
Shanghai	51.5	1.00	50.4	0.98	45.4	0.88	46.2	0.90
Chengdu	11.2	1.00	12.3	1.10	13.0	1.16	15.1	1.35
Chongqing	25.4	1.00	26.5	1.04	28.0	1.10	30.2	1.19
Urban average	23.7	1.00	24.5	1.03	23.5	0.99	25.5	1.07

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

Table 5-5 Annual average $PM_{2.5}$ concentration trends under the BAU scenario*

	2005		2010		2020		2030	
	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio
National average	10.2	1.00	11.5	1.13	10.4	1.02	11.3	1.10
Beijing	59.6	1.00	62.2	1.04	60.6	1.02	62.5	1.05
Tianjin	70.7	1.00	72.6	1.03	71.4	1.01	73.1	1.03
Shenyang	52.6	1.00	55.0	1.05	53.3	1.01	54.7	1.04
Jinan	66.1	1.00	69.8	1.06	67.1	1.01	70.0	1.06
Shijiazhuang	68.8	1.00	72.1	1.05	70.0	1.02	72.1	1.05
Zhengzhou	69.4	1.00	74.8	1.08	71.0	1.02	74.3	1.07
Wuhan	62.0	1.00	67.7	1.09	62.9	1.02	67.0	1.08
Hefei	45.6	1.00	50.1	1.10	46.4	1.02	49.7	1.09
Nanjing	44.6	1.00	48.5	1.09	45.4	1.02	48.1	1.08
Shanghai	45.5	1.00	49.1	1.08	46.2	1.02	48.6	1.07
Chengdu	62.5	1.00	71.8	1.15	64.7	1.04	70.9	1.13
Chongqing	70.1	1.00	77.8	1.11	71.5	1.02	76.3	1.09
Urban average	59.8	1.00	64.3	1.08	60.9	1.02	63.9	1.07

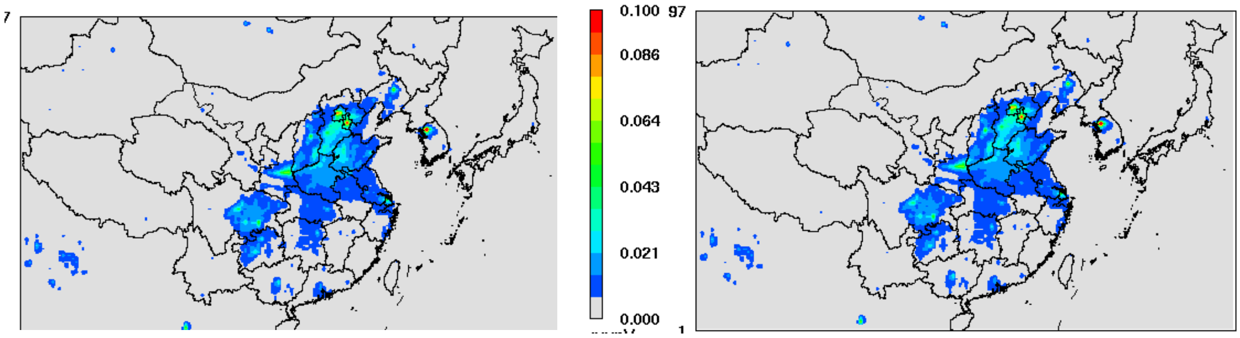
* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

5.3.2 S1 Scenario (BAU+CCP)

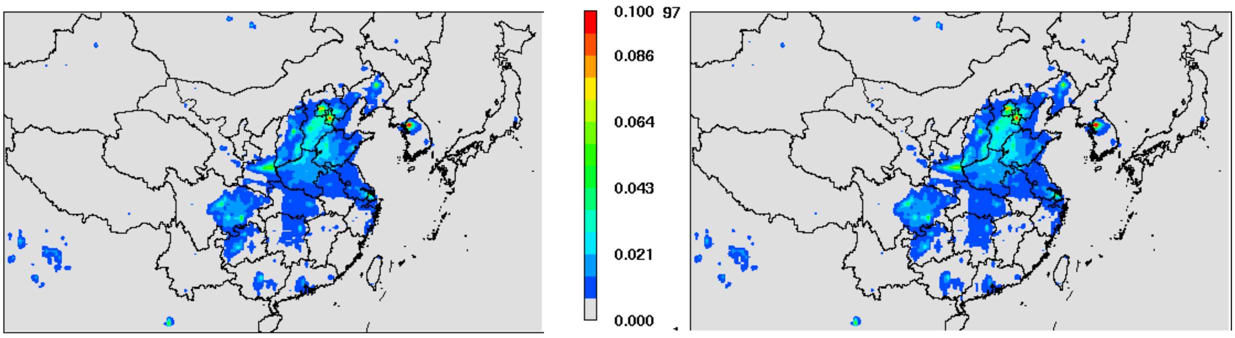
In Scenario 1, the key assumptions of CCP included a more rapid decline in energy intensity in the industrial sector, the application of more energy saving appliances in the residential sector, significant improvement in energy conservation standards for building and the replacement of more dispersed heating supplies by centralized ones, an increase in automobile fuel economy, increased efficiency in electricity plants and heat boilers, etc. The energy-related ambient concentrations of the pollutants in the target years (2005, 2010, 2020, and 2030) are shown in Figure5-12~14. The concentration trends under the S1 scenarios are shown in Table 5-6~8.

According to the simulation results, the contribution of energy activities to the concentration of the three pollutants will decrease in S1 compared to BAU. However the contribution to emissions from energy consumption will keep gradually increasing compared to base year concentration. The heavily polluted areas in the middle, east and southwest of China will be constrained in the same domain as 2005 in 2030. According to the simulation results, the energy-related SO_2 concentrations will be greatly reduced. During 2005 and 2030, the contribution of energy activities to SO_2 concentration will gradually increase, but at a lower growth rate than that of BAU due to the promotion of CCP policies. The energy-related $S0_2$ concentration will increase more rapidly than NO_2 and $PM_{2.5}$, increasing the national average by 9% from 4.3 ug/m^3 in 2005 to 4.7 ug/m^3 in 2030. For the 12 urban cities, the average value will increase from 62.5 ug/m^3 in 2005 to 68.1 ug/m^3 in 2030. The most rapidly increasing ratios are found in three heavily polluted areas: the middle area including Beijing, Tianjin and Senyang, the eastern Changjiang river delta area including Zhengzhou, Wuhan, Hefei and Nanjing, and the southwestern area including Chongqing and Sichuan. The areas with high energy-related NO_2 concentrations are distributed in the three highly polluted areas, which are similar to those of SO_2. However, the absolute concentration remains almost the same from 2005 to 2030. The national average increases by only 0.1 ug/m^3 from 2005 to 2030, from 2.2 ug/m^3 to 2.3 ug/m$^{3/}$. In the 12 urban cities, the average value increases very little, from 23.5 ug/m^3 in 2005 to 23.6 ug/m^3 in 2030.

In Scenario 1, the contribution of energy activities to $PM_{2.5}$ concentration will increase more rapidly than in BAU. $PM_{2.5}$ concentration will increase by 7% at the national level, from 10.2ug/m^3 in 2005 to 10.9ug/m^3 in 2030. For the 12 urban cities, it will increase from 59.5 ug/m^3 to 61.8 ug/m^3, with the most rapid increase of 62.1 ug/m^3 to 68.5 ug/m^3 occuring in Chengdu in the southwest of China. The areas with the highest energy-related $PM_{2.5}$ concentrations are distributed in the three highly polluted areas in middle, eastern and southwestern China.

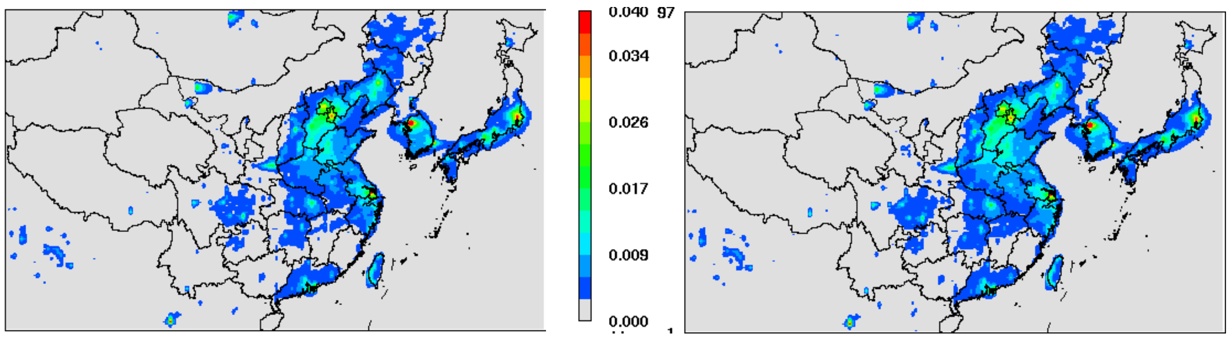


(a) 2005 (b) 2010

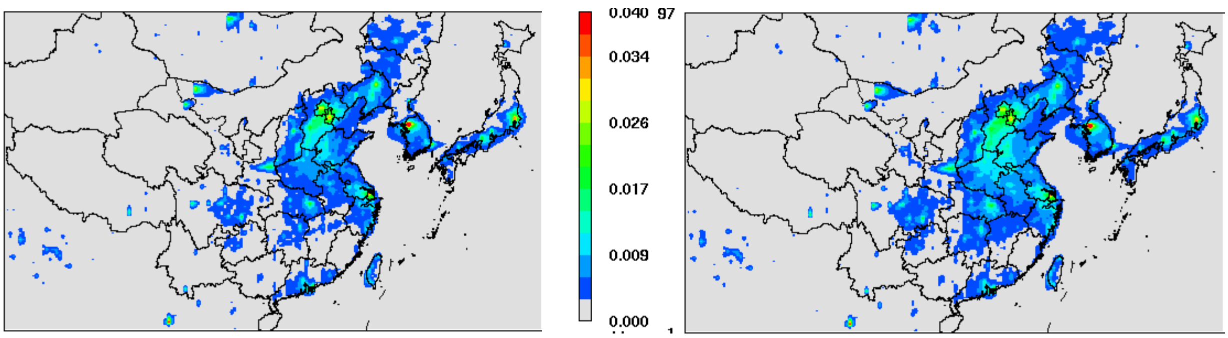


(c) 2020 (d) 2030

Figure 5-12 Average Concentration distribution of SO_2 under the S1 scenario in Jan (unit: ppm)

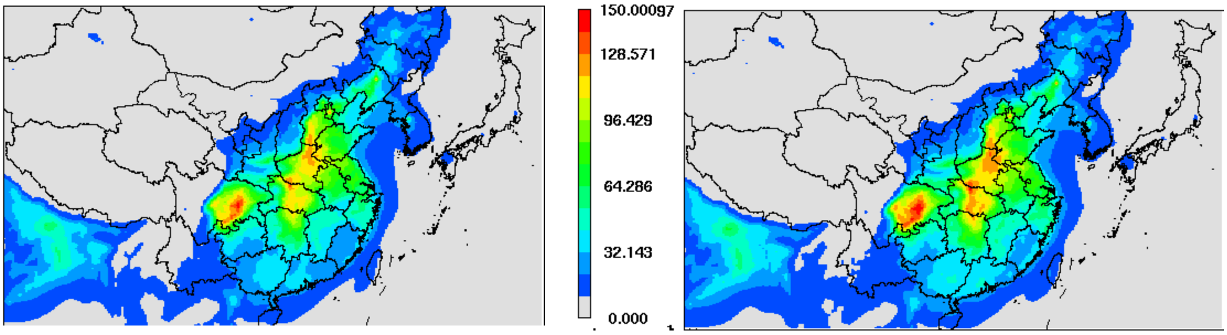


(a) 2005 (b) 2010

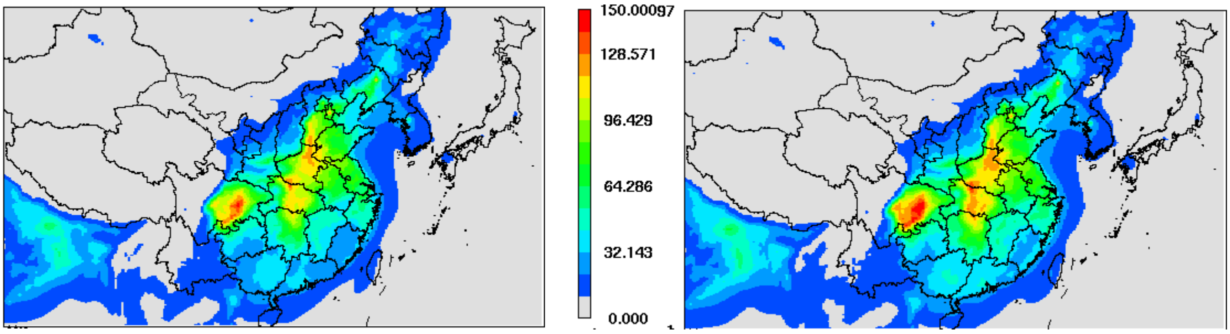


(c) 2020 (d) 2030

Figure 5-13 Average Concentration distribution of NO_2 under the S1 scenario in Jan (unit: ppm)



(a) 2005 (b) 2010



(c) 2020 (d) 2030

Figure 5-14 Average Concentration distribution of $PM_{2.5}$ under the S1 scenario in Jan (unit:ug/m^3)

Table 5- 6 Annual average SO_2 concentrations trend under the S1 scenario*

	2005		2010		2020		2030	
	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio
National average	4.3	1.00	4.4	1.01	4.4	1.03	4.7	1.09
Beijing	120.0	1.00	119.0	0.99	121.5	1.01	126.4	1.05
Tianjin	109.5	1.00	109.7	1.00	114.6	1.05	119.4	1.09
Shenyang	52.0	1.00	53.8	1.03	57.9	1.11	61.6	1.18
Jinan	86.0	1.00	86.5	1.01	88.5	1.03	90.4	1.05
Shijiazhuang	34.2	1.00	34.3	1.00	35.7	1.04	37.2	1.09
Zhengzhou	32.6	1.00	32.9	1.01	34.1	1.05	36.1	1.11
Wuhan	30.2	1.00	30.5	1.01	32.0	1.06	33.4	1.11
Hefei	20.4	1.00	20.8	1.02	21.8	1.07	23.1	1.13
Nanjing	20.5	1.00	20.9	1.02	21.9	1.07	22.9	1.11
Shanghai	76.4	1.00	77.8	1.02	83.0	1.09	86.9	1.14
Chengdu	58.6	1.00	58.8	1.00	61.4	1.05	64.7	1.11
Chongqing	110.0	1.00	108.4	0.99	113.0	1.03	115.3	1.05
Urban average	62.5	1.00	62.8	1.00	65.4	1.05	68.1	1.09

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

Table 5-7 Annual average NO_2 concentrations trend under the S1 scenario*

	2005		2010		2020		2030	
	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio
National average	2.2	1.00	2.4	1.07	2.0	0.91	2.3	1.04
Beijing	41.6	1.00	41.1	0.99	38.2	0.92	38.7	0.93
Tianjin	44.3	1.00	44.0	0.99	39.9	0.90	40.3	0.91
Shenyang	24.7	1.00	24.8	1.00	24.1	0.97	24.6	0.99
Jinan	24.8	1.00	25.4	1.02	22.6	0.91	23.7	0.96
Shijiazhuang	10.8	1.00	12.3	1.14	10.2	0.94	13.0	1.21
Zhengzhou	9.7	1.00	11.0	1.14	9.8	1.02	12.6	1.31
Wuhan	17.7	1.00	18.7	1.06	18.3	1.03	20.6	1.17
Hefei	9.9	1.00	10.9	1.11	10.3	1.04	12.4	1.25
Nanjing	11.0	1.00	11.8	1.07	10.3	0.93	12.0	1.10
Shanghai	51.3	1.00	50.7	0.99	43.9	0.86	43.7	0.85
Chengdu	10.9	1.00	11.6	1.07	11.5	1.05	13.4	1.23
Chongqing	25.1	1.00	25.7	1.02	26.2	1.05	27.9	1.11
Urban average	23.5	1.00	24.0	1.02	22.1	0.94	23.6	1.00

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

Table 5-8 Annual average $PM_{2.5}$ concentrations trend under the S1 scenario*

	2005		2010		2020		2030	
	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio
National average	10.2	1.00	10.8	1.06	10.2	1.00	10.9	1.07
Beijing	59.3	1.00	60.4	1.02	59.4	1.00	60.3	1.02
Tianjin	70.5	1.00	71.9	1.02	70.2	1.00	71.0	1.01
Shenyang	52.5	1.00	53.3	1.02	52.6	1.00	53.7	1.02
Jinan	65.8	1.00	68.0	1.03	65.6	1.00	67.4	1.02
Shijiazhuang	68.5	1.00	70.2	1.03	68.5	1.00	69.3	1.01
Zhengzhou	69.0	1.00	71.4	1.03	69.3	1.00	71.3	1.03
Wuhan	61.7	1.00	65.3	1.06	61.4	1.00	64.7	1.05
Hefei	45.4	1.00	48.0	1.06	45.2	1.00	47.7	1.05
Nanjing	44.4	1.00	46.5	1.05	44.2	1.00	46.1	1.04
Shanghai	45.3	1.00	47.2	1.04	45.3	1.00	47.0	1.04
Chengdu	62.1	1.00	66.6	1.07	62.7	1.01	68.5	1.10
Chongqing	69.6	1.00	73.6	1.06	69.4	1.00	74.0	1.06
Urban average	59.5	1.00	61.9	1.04	59.5	1.00	61.8	1.04

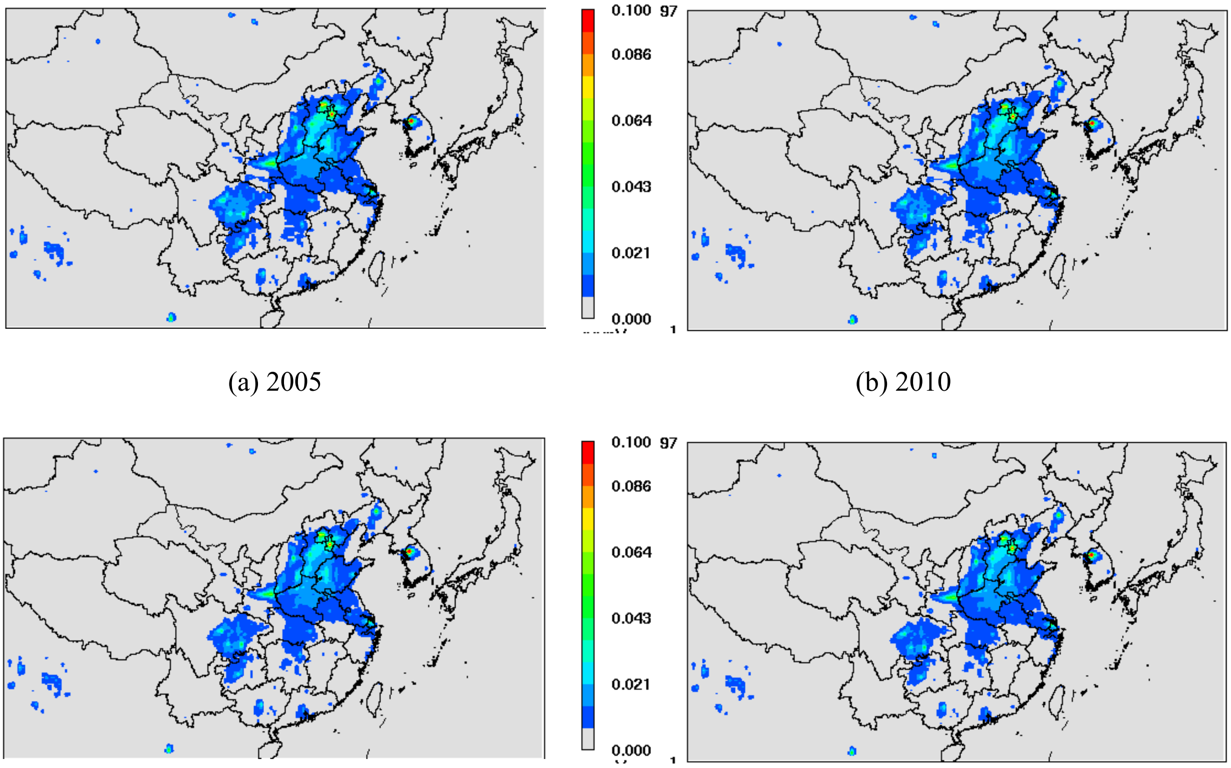
* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

5.3.3 S2 Scenario (BAU+CCP+PCP)

Scenario 2 assumes a higher level of pollution control policies (PCP) besides CCP policies in Scenario 1. The key assumptions of PCP include: accelerated replacement of small power plants by larger ones with FGD, more widespread use of NOx control technologies beginning in 2012, improvement in control efficiency of SO_2 and NOx in industrial sectors, more focused PM control, additional installation of ESP and baghouse, enforcement of the EUROIII standard for mobile sources beginning in 2008, the EUROIV standard in 2010, and more strict standards in 2015, 2020, and beyond. The energy-related ambient concentrations of the pollutants in the target years (2005, 2010, 2020, and 2030) are shown in Figure 5-15~17. The concentration trends under the S2 scenario are shown in Table 5-9~11.

The simulation results indicate that the concentrations of SO_2 are further reduced from the results of Scenario 1. The national average SO_2 concentration will decrease by 13% versus BAU, from 4.2 ug/m^3 in 2005 to 3.7 ug/m^3 in 2030. For the 12 urban cities, the average value will decrease from 61.2 ug/m^3 in 2005 to 57.5 ug/m^3 in 2030, 3.7ug/m^3 lower than that in BAU. This reduction is caused by the energy efficiency and pollutants control policies included in Scenario 2, which slow down the growth rate of total energy consumption and control pollutants emissions. For NO_2, the decreasing trend is quite similar to that of SO_2.

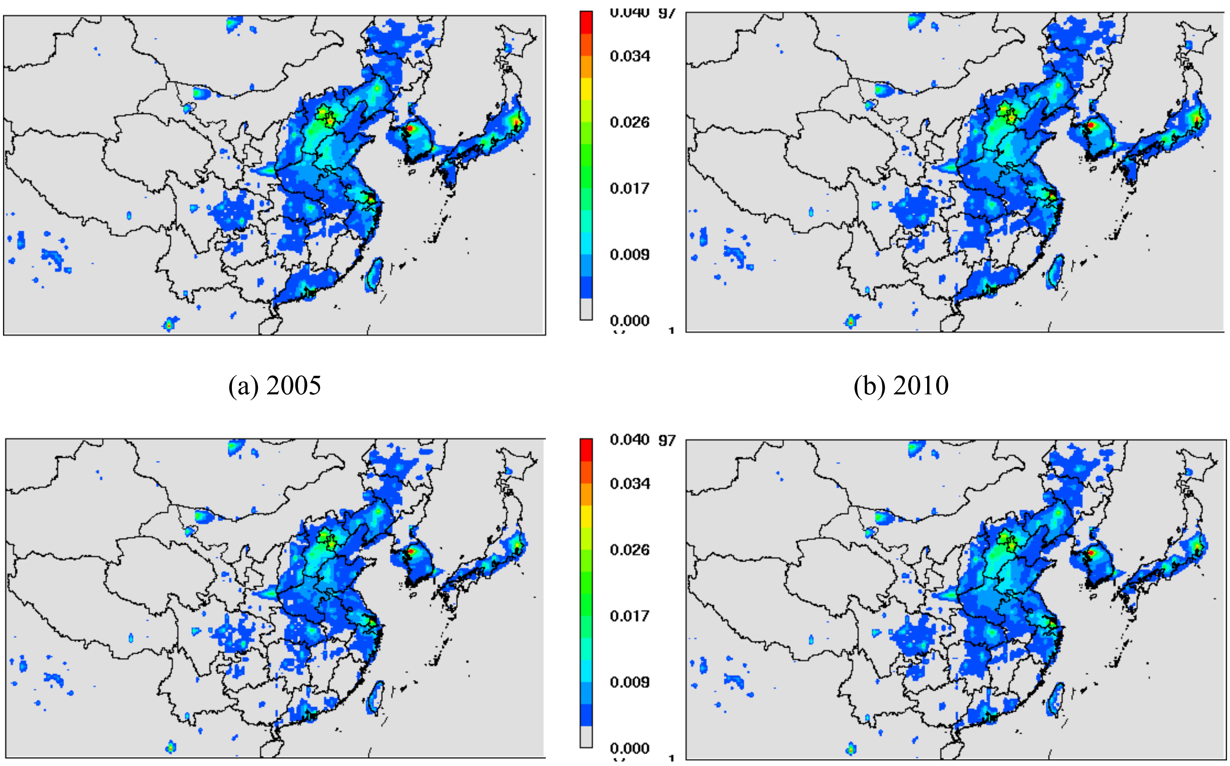
In Scenario 2, the contribution of energy activities to $PM_{2.5}$ concentration will increase at first before decreasing in future years. The $PM_{2.5}$ concentration will initially increase at a reduced rate until the peak average of 10.2ug/m^3 nationally and 59.5ug/m^3 for the 12 urban cities is reached in 2010. $PM_{2.5}$ concentration will then decrease, reaching a national average of 9.2 ug/m^3 and 57.9ug/m^3 for the 12 urban cities in 2030. This variation trend in $PM_{2.5}$ will occur as a result of a slow down in sectors' energy demand and the assumed implementation of fuel economy standards for light duty vehicles in the transportation sector after 2010, which will cause rapid reduction in $PM_{2.5}$ concentration in 2020 and 2030.



(a) 2005 (b) 2010

(c) 2020 (d) 2030

Figure 5-15 Average Concentration distribution of SO_2 under the S2 scenario in Jan (unit: ppm)



(a) 2005 (b) 2010

(c) 2020 (d) 2030

Figure 5-16 Average Concentration distribution of NO_2 under the S2 scenario in Jan (unit: ppm)

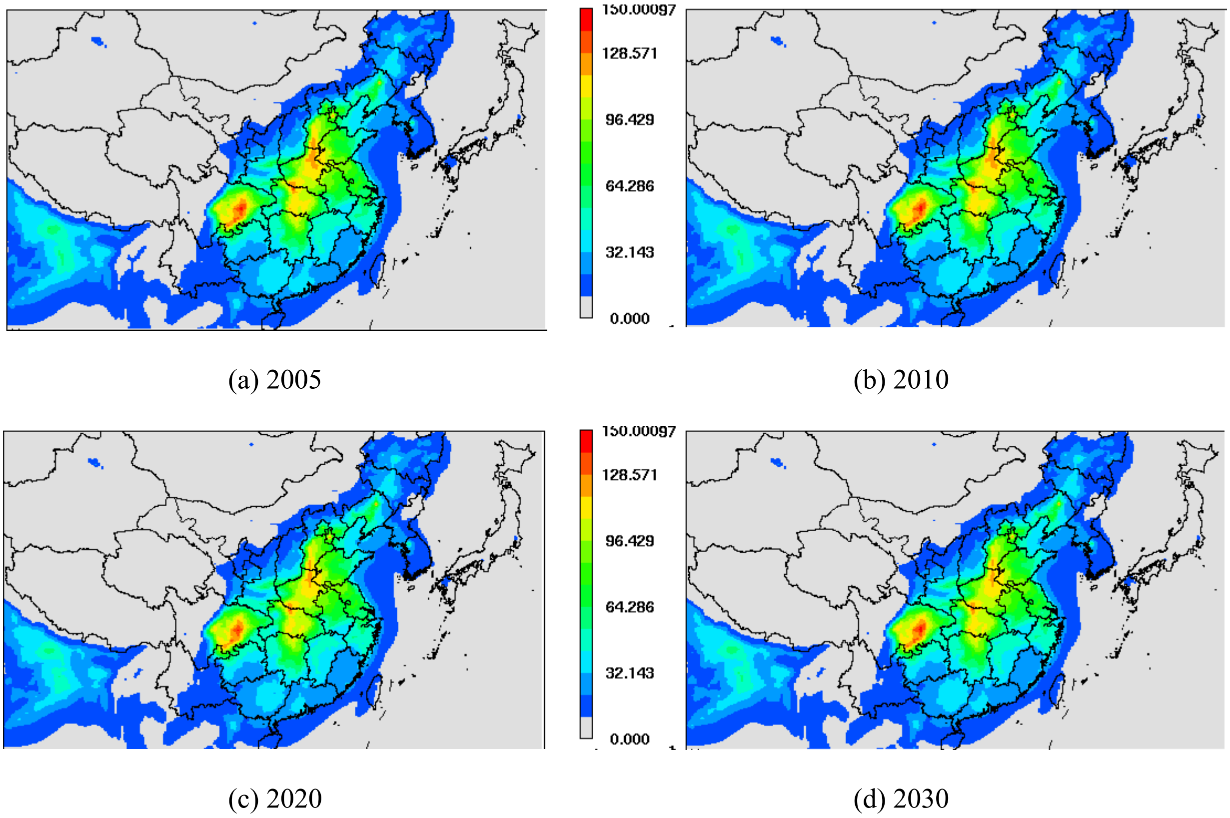


Figure 5-17 Average Concentration distribution of $PM_{2.5}$ under the S2 scenario in Jan (unit:ug/m^3)

Table 5-9 Annual average SO_2 concentrations trend under the S2 scenario*

	2005		2010		2020		2030	
	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio
National average	4.2	1.00	4.1	0.97	3.9	0.92	3.7	0.87
Beijing	116.9	1.00	111.5	0.95	107.3	0.92	104.8	0.90
Tianjin	106.8	1.00	103.6	0.97	101.2	0.95	99.2	0.93
Shenyang	50.7	1.00	50.7	1.00	50.9	1.00	50.3	0.99
Jinan	85.1	1.00	84.6	0.99	84.0	0.99	83.5	0.98
Shijiazhuang	33.3	1.00	32.4	0.97	31.3	0.94	30.6	0.92
Zhengzhou	31.8	1.00	30.9	0.97	29.7	0.93	28.9	0.91
Wuhan	29.5	1.00	29.1	0.99	28.5	0.96	27.9	0.94
Hefei	20.0	1.00	19.8	0.99	18.9	0.94	18.0	0.90
Nanjing	20.2	1.00	20.1	1.00	19.9	0.99	19.7	0.98
Shanghai	74.7	1.00	74.2	0.99	74.1	0.99	73.4	0.98
Chengdu	56.9	1.00	54.9	0.96	53.2	0.94	52.1	0.91
Chongqing	107.9	1.00	105.1	0.97	102.9	0.95	101.4	0.94
Urban average	61.2	1.00	59.7	0.98	58.5	0.96	57.5	0.94

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

Table 5-10 Annual average NO_2 concentrations trend under the S2 scenario*

	2005		2010		2020		2030	
	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio	Concentration ($\mu g/m^3$)	Ratio
National average	2.2	1.00	2.2	1.00	2.0	0.89	1.8	0.82
Beijing	41.3	1.00	40.6	0.98	36.6	0.89	35.3	0.85
Tianjin	44.0	1.00	43.3	0.98	38.0	0.86	36.6	0.83
Shenyang	24.5	1.00	24.6	1.00	23.1	0.94	22.4	0.91
Jinan	24.7	1.00	24.4	0.99	22.3	0.90	21.4	0.87
Shijiazhuang	10.7	1.00	10.6	0.99	10.6	0.99	9.2	0.86
Zhengzhou	9.6	1.00	9.6	1.01	10.1	1.06	8.9	0.93
Wuhan	17.5	1.00	17.7	1.01	18.2	1.04	17.0	0.97
Hefei	9.8	1.00	10.0	1.02	10.2	1.04	9.3	0.95
Nanjing	10.9	1.00	10.9	1.00	10.5	0.96	9.5	0.87
Shanghai	51.1	1.00	50.1	0.98	41.7	0.82	40.3	0.79
Chengdu	10.8	1.00	11.0	1.02	11.5	1.07	10.4	0.97
Chongqing	24.9	1.00	25.1	1.01	26.1	1.05	25.0	1.00
Urban average	23.3	1.00	23.2	0.99	21.6	0.92	20.4	0.88

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all compared to the year of 2005.

Table 5-11 Annual Average $PM_{2.5}$ concentrations trend under the S2 scenario*

	2005		2010		2020		2030	
	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio	Concentration (μg/m^3)	Ratio
National average	10.2	1.00	10.2	1.00	9.8	0.97	9.8	0.97
Beijing	59.1	1.00	59.2	1.00	57.7	0.98	57.5	0.97
Tianjin	70.3	1.00	70.4	1.00	68.5	0.97	67.9	0.97
Shenyang	52.4	1.00	52.4	1.00	51.8	0.99	51.7	0.99
Jinan	65.6	1.00	65.7	1.00	63.8	0.97	63.6	0.97
Shijiazhuang	68.3	1.00	68.5	1.00	66.7	0.98	66.1	0.97
Zhengzhou	68.8	1.00	68.9	1.00	67.3	0.98	67.1	0.98
Wuhan	61.5	1.00	61.7	1.00	59.8	0.97	59.8	0.97
Hefei	45.2	1.00	45.3	1.00	43.8	0.97	43.9	0.97
Nanjing	44.2	1.00	44.4	1.00	42.9	0.97	42.8	0.97
Shanghai	45.2	1.00	45.3	1.00	44.1	0.98	43.9	0.97
Chengdu	61.9	1.00	62.1	1.00	60.9	0.98	61.7	1.00
Chongqing	69.4	1.00	69.7	1.00	67.6	0.97	68.3	0.98
Urban average	59.3	1.00	59.5	1.00	57.9	0.98	57.9	0.98

* national average refers to the average of all the areas included in the modeling domain; urban average refers to the average of the 12 cities listed above; ratios are all

compared to the year of 2005.

5.3.4 Improvement of air quality

Figures 5-18~20 show the SO_2 concentration reduction distribution between different scenarios in 2030. The improvement in air quality under CCP, PCP and CCP+PCP scenarios for different areas are shown separately.

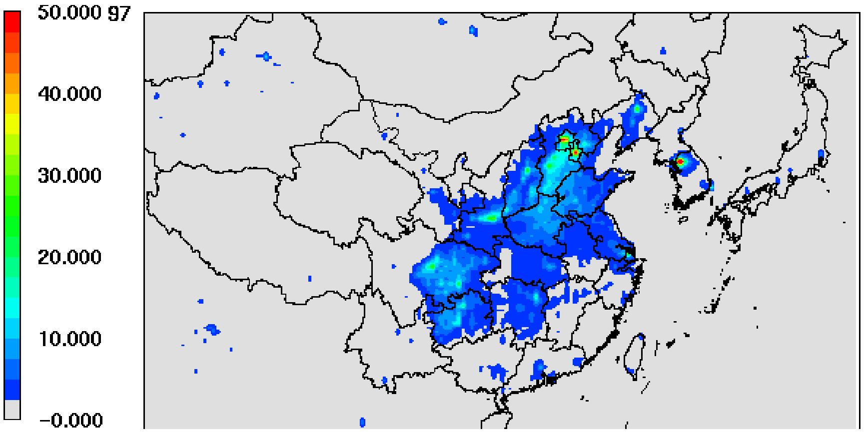


Figure 5-18 SO_2 concentration reduction from BAU to S1 in 2030 (unit: ug/m^3)

Effects of CCP policies for SO_2

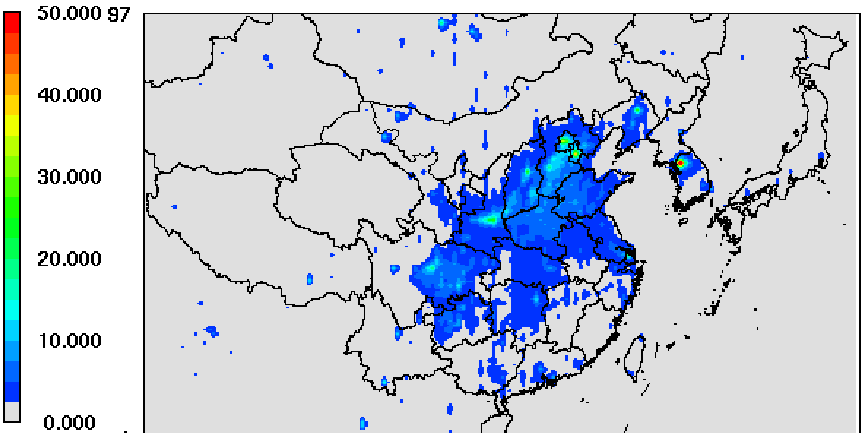


Figure 5-19 SO_2 concentration reduction from S1 to S2 in 2030 (unit: ug/m^3)

Effects of PCP policies for SO_2

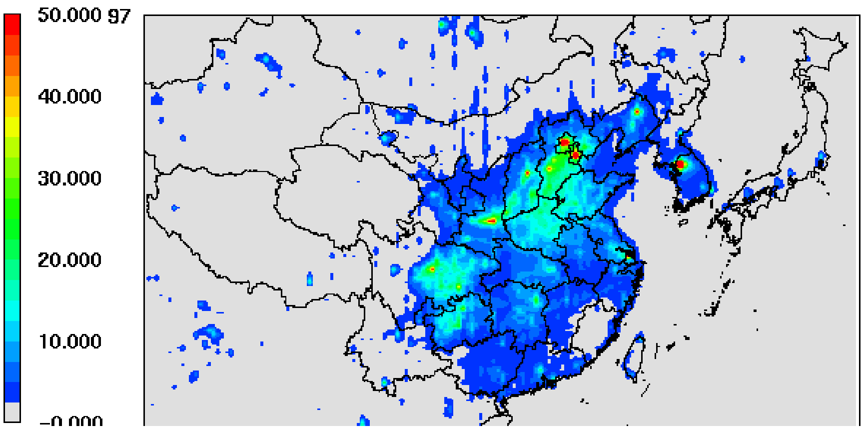


Figure 5-20 SO_2 concentration reduction from BAU to S2 in 2030 (unit: ug/m^3)

Effects of CCP+PCP policies for SO_2

The results show that concentrations of SO_2 are reduced in Scenario 1 and Scenario 2 by the energy efficiency (CCP) and pollutants control policies (PCP), which slow down the growth rate of total energy consumption and control the emission of pollutants. The distribution and intensity of concentration benefits of CCP and PCP policies are mostly the same for SO_2. The greatest effects are found in the three most heavily polluted areas: the middle area including Beijing, Tianjin and Senyang, the eastern Changjiang river delta area including Zhengzhou, Wuhan, Hefei and Nanjing , and the southwestern area including Chongqing and Sichuan.

The average benefits of CCP, PCP and CCP+PCP policies are shown in figures 5-21~22, which display the SO_2 national average and 12 urban cities average under the different scenarios

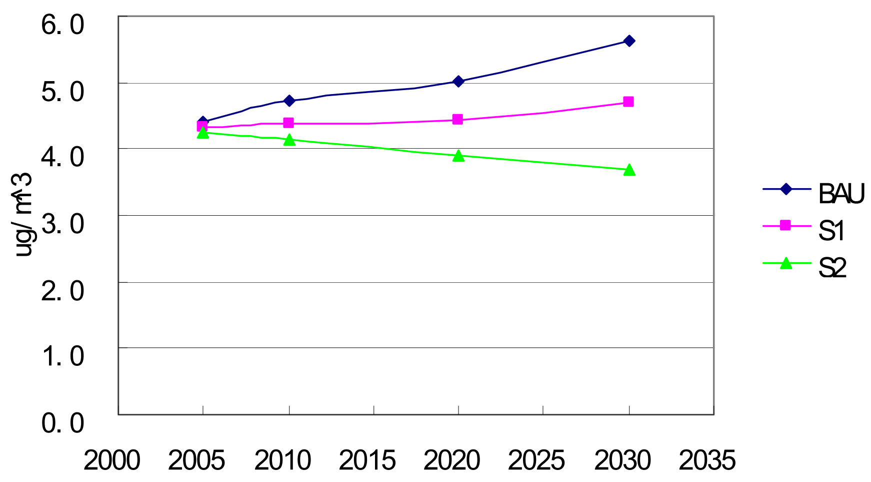


Figure5-21 SO_2 National Average Concentration under different scenarios

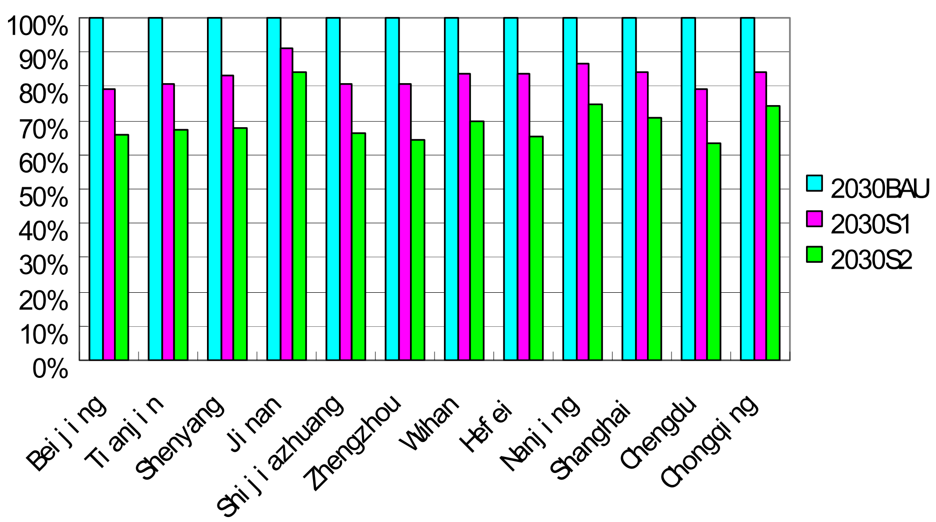


Figure 5-22 SO_2 concentration reduction for urban cities in 2030 (unit: ug/m^3)

The improvement in air quality and reduction in $PM_{2.5}$ concentration in 2030 under the CCP, PCP and CCP+PCP scenarios are shown separately in.figures 5-23 to 5-25.

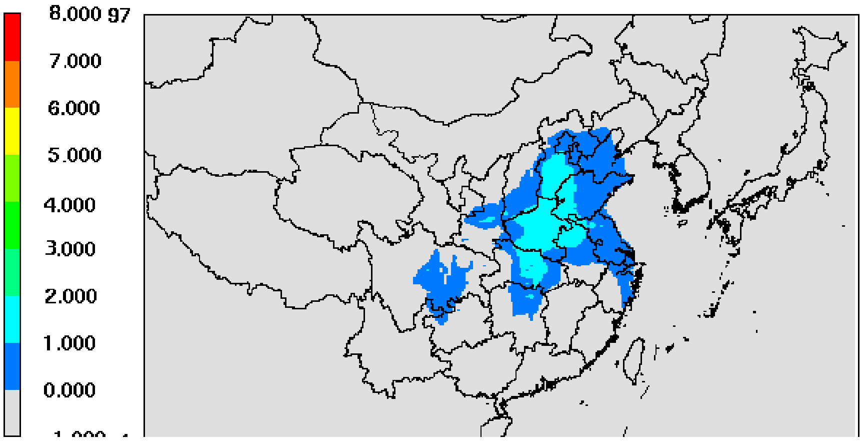


Figure 5-23 $PM_{2.5}$ concentration reduction from BAU to S1 in 2030 (unit: ug/m^3)

Effects of CCP policies for PM2.5

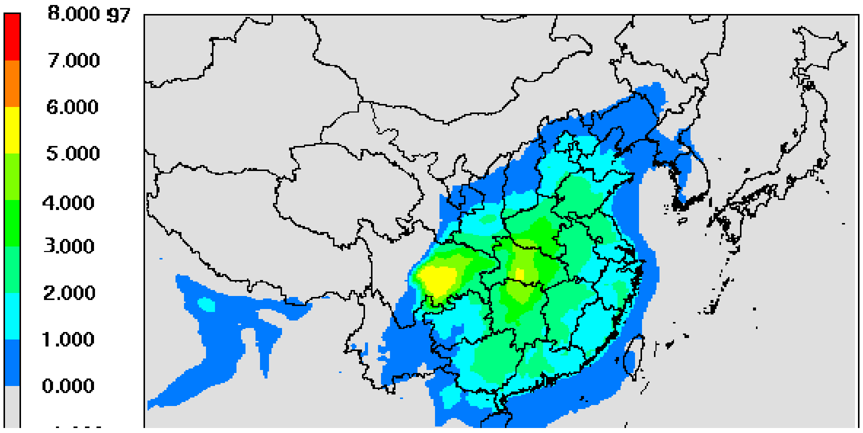


Figure 5-24 $PM_{2.5}$ concentration reduction from S1 to S2 in 2030 (unit: ug/m^3)

Effects of PCP policies for PM2.5

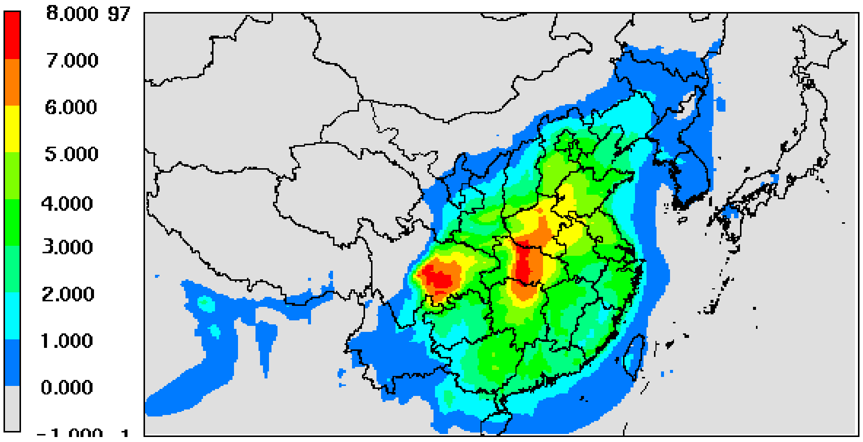


Figure 5-25 $PM_{2.5}$ concentration reduction from BAU to S2 in 2030 (unit: ug/m^3)

Effects of CCP+PCP policies for $PM_{2.5}$

The results show that pollutants control policies (PCP) have more benefits than CCP policies for $PM_{2.5}$ distribution and intensity. Similarly to the SO_2 results, the largest effects are in the three heavily polluted areas: the middle area including Beijing, Tianjin and Senyang, the eastern Changjiang river delta area including Zhengzhou, Wuhan, Hefei and Nanjing, and the southwestern area including Chongqing and Sichuan

Figures 5-26~27 show the $PM_{2.5}$ national average and 12 urban cities average concentration under the CCP, PCP and CCP+PCP policies. The projections for energy-related $PM_{2.5}$ concentration are somewhat complicated for future years. There are two reasons for this.

First, the primary $PM_{2.5}$ emissions are from multiple sources. Although energy-related BC and OC comprise a large share of the sources of $PM_{2.5}$, other sources such as industry processes, including cement and lime, and the fugitive $PM_{2.5}$ from construction and transportation are also very important. For example, the total BC and OC emissions share of $PM_{2.5}$ is only 42% in the base year of 2001. In all the scenarios of this study, only the energy-related BC and OC emissions are controlled, because $PM_{2.5}$ emissions from other sources, such as the industry processes, construction and transportation, are assumed to remain the same as in the base year.

Secondly, the total $PM_{2.5}$ concentration is complicated because $PM_{2.5}$ in the atmosphere includes both primary species directly from emissions and secondary species produced by precursor emissions of SO_2 and NOx. In Beijing, for example, in 2001 the annual average concentration ratio of total BC and OC species in $PM_{2.5}$ is about 35%, the ratio of total secondary species such as sulfate，ammonium and nitrate is about 25%, and the other species directly from or produced by emissions of other sources share a ratio of 40%. In this case, at least 40% of the $PM_{2.5}$ concentration in Beijing will not be significantly affected by the scenarios in this study. Although no $PM_{2.5}$ species information is available at the national level, the preliminary determination is that a significant part of $PM_{2.5}$ concentration is not directly affected in this study.

For the decreasing BC and OC from energy-related sectors, however, increasing SO_2 and NO_2 in corresponding sectors combined with other sources such as fugitive dust cause the $PM_{2.5}$ concentration to reach its peak value in 2010 and turning point in 2020. In Scenario 2 (CCP+PCP), $PM_{2.5}$ concentration will continue to gradually decrease at the national level. In 2030, all urban cities will experience a benefit of 10% in Scenario 2. This result indicates that PM concentration cannot meet the goal if policy measures only focus on energy. Other measures should be implemented to control PM pollution.

Additionally, the concentration level trends for each pollutant did not always monotonically increase or decrease in each scenario. Some discussion of these phenomena follows.

The sources of SO_2 are almost all energy-related. In BAU and S1 scenarios, the energy-related SO_2 emissions keep increasing and most of the sources of SO_2 keep increasing. As a result, SO_2 emission increases very quickly from 2005 to 2030 in BAU and S1 scenarios. The emission levels and concentration levels demonstrate an almost linear relationship.

The PM is from multi-sources and in multi-species. The PM emission and concentrations relationship is not linear. Energy-related primary BC and OC keeps decreasing from 2005-2030 in BAU and S1 scenarios, but energy-related precursors that leads to secondary sulfates and nitrates, such as SO_2 and NOx, keep increasing. From 2010 to 2020, the decreasing trend of BC and OC is more significant than the increasing trend of SO_2 and NOx, so the primary species decrease much more than secondary species increase. The total PM concentration from 2010 to 2020 is decreasing. From 2020 to 2030, combining the opposed emission trends and complicated PM reaction mechanism, the total PM concentration reaches a turning point in 2020 and increases from 2020 to 2030.

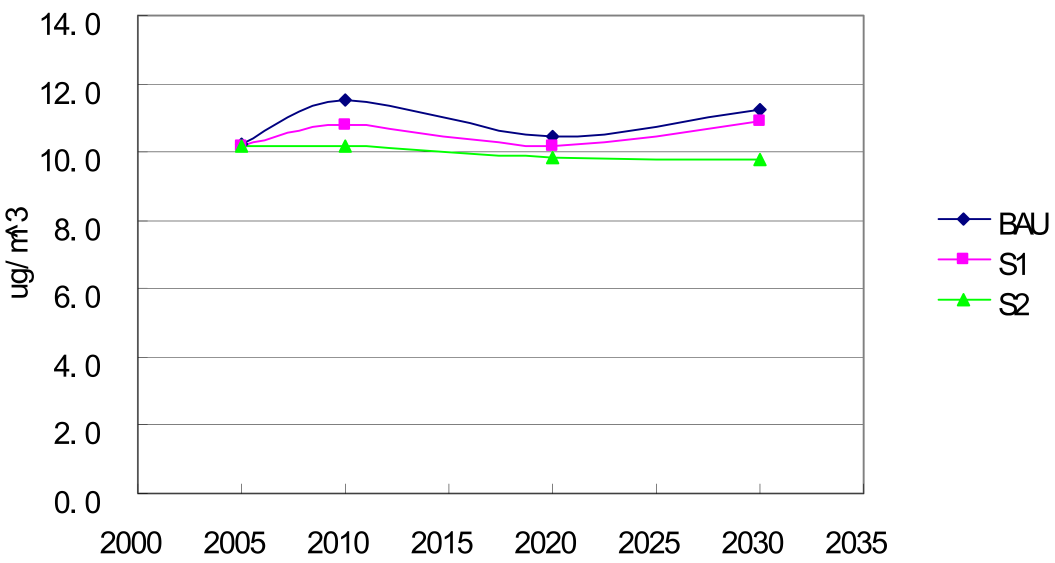


Figure 5-26 $PM_{2.5}$ National Average Concentration under different scenarios

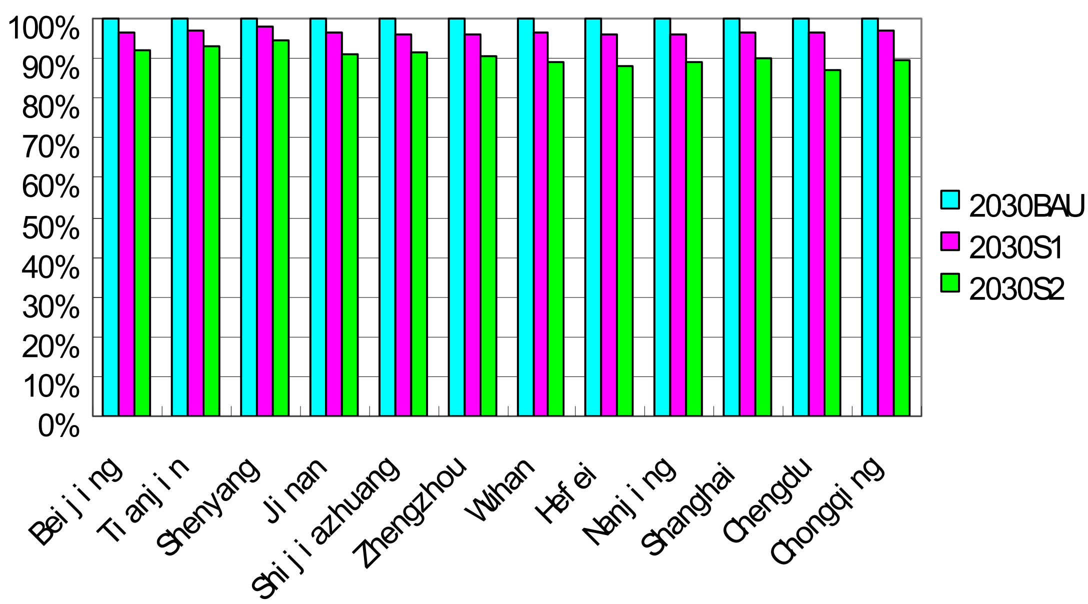


Figure 5-27 $PM_{2.5}$ concentration reduction for urban cities in 2030 (unit: ug/m^3)

CHAPTER 6 HEALTH BENEFIT ANALYSIS

This assessment uses the BenMAP model developed by the U.S. EPA to perform the health benefits and economic valuation analyses associated with changes in air quality from implementation of the two different energy scenarios in China (PCP and CCP).

BenMAP is primarily intended as a tool for estimating the health impacts and associated economic values resulting from changes in ambient air pollution. It accomplishes this by running concentration-response functions (C-R functions), which relate a change in the concentration of a pollutant with a change in the incidence of a health endpoint. Inputs to C-R functions typically include: (a) the change in pollutant concentration and associated change in incidence, (b) the exposed population, and (c) the baseline incidence rate of the health endpoint. Economic values for the incidence changes can then be estimated by multiplying the change in incidence by an estimated unit value for the health endpoint.

Figure 6-1 summarizes the flow of calculations in BenMAP, and the types of choices made, such as the population of interest, the types of the health effects to model, and how to place an economic value on these health effects. This exhibit also highlights that the BenMAP model does not have air modeling capabilities and instead relies on modeling and monitoring inputs.

In this assessment, air quality data were provided by the CMAQ output described in chapter 5. The CMAQ output air pollutant concentrations under the different energy scenarios were transformed in accordance with the input requirements of the BenMAP model.

The following section describes the methodology and data preparation for BenMAP modeling, including the concentration-response functions, baseline health incidence, population exposure and economic valuation functions.

6.1 Methodology and data

The previous chapter noted that government policies for climate change and pollution control have the potential to reduce emissions and correspondingly reduce human exposure to air pollution. In the case of policies aimed at mitigating greenhouse gas emissions, the reduction in pollutants harmful to human health represents an ancillary benefit. This chapter presents the methods and materials used in the present analysis including key issues in the estimation of health benefits analysis and in the valuation of health benefits.

6.1.1 Population Exposure

6.1.1.1 Selection of air pollution indicator

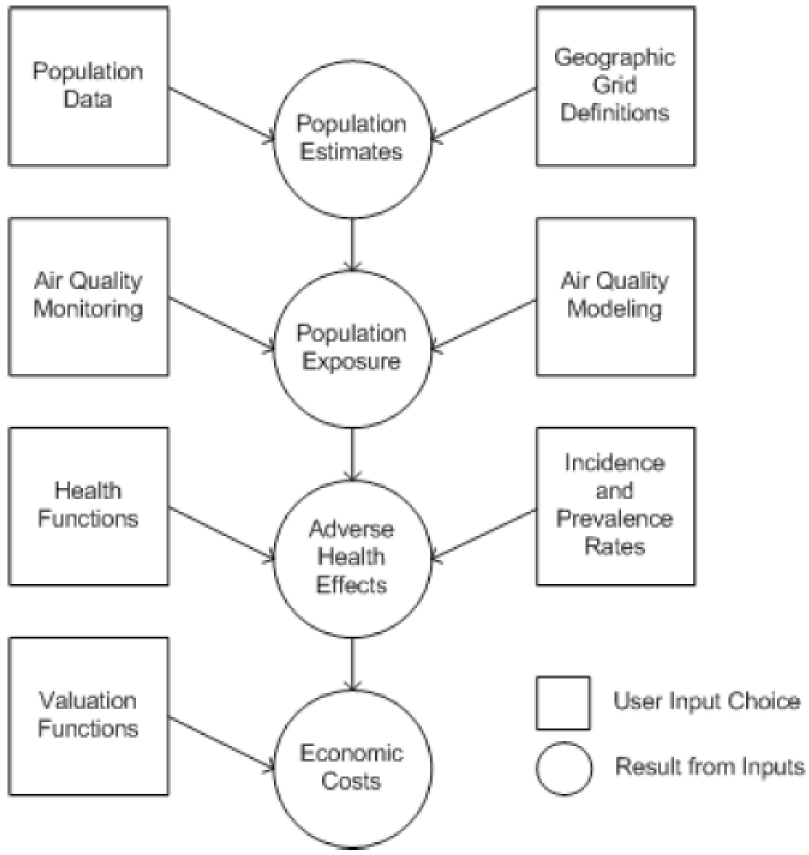


Figure 6-1 BenMAP Flow Diagram

The 2001 air quality monitoring data from Chinese cities (SEPA 2002) showed that among the 341 monitored cities, only 33.4% of cities reached the national standard for Class II, and particulate matter less than 10 µm in diameter was the main pollutant in most of the cities. Various air pollutants have a synergetic effect on human health. Although many studies have been connected, the effect of each pollutant on health is still difficult to quantify. A large number of epidemiological studies have shown that particulate matter under 10 µm contains toxic and hazardous matter and is closely related to negative health effects. Because it is a pollutant of great concern in China, PM was chosen as the pollutant indicator in the health assessment.

Although China has traditionally recorded high SO_2 concentrations, they have decreased dramatically in recent years in most Chinese cities, with average levels in some cities below the WHO air quality guideline of $50 \mu g/m^3$ (2000). Furthermore, the health effects of SO_2 emissions may be partially accounted for in the health effect estimates from PM since PM includes sulfate aerosol. It was for these reasons that PM was chosen as the sole indicator in the final assessment. This prevents issues with the double counting problem, but it will not capture the health benefits from reduction in non-sulfate SO_2 impacts, which may underestimate the health benefits from the air pollution reduction in China.

The CMAQ model output provides $PM_{2.5}$ concentrations and long-term concentration-response functions derived from a U.S. cohort study indexed by $PM_{2.5}$. Though effect estimates of short term exposure on health rely on PM_{10} concentrations, the benefits from long-term air pollution reduction contribute over 80% of the total benefits. To minimize uncertainty, $PM_{2.5}$ was used as the indicator of air pollution and concentration-response coefficients based on PM_{10} concentrations were converted into coefficients as a function of $PM_{2.5}$.

6.1.1.2 Population exposure

The exposed population in this assessment is all China residents, including urban and rural populations. Population growth over the study period was taken into account. The population was 1.28 billion in 2001, and projections estimate it will be 1.525 billion in 2030. The estimated population in future years is shown in table 6-1, and the corresponding population density distribution in 2005 is shown in figure 6-2.

Table 6-1 Population and growth rate in China between 2001 and 2030

Year	Population size (billion)	Annual growth rate (%)
2001	1.28	—
2005	1.32	0.77
2010	1.38	0.89
2020	1.47	0.63
2030	1.53	0.40

Note: Energy Research Institute's 2003 Projection on basic economic and energy information

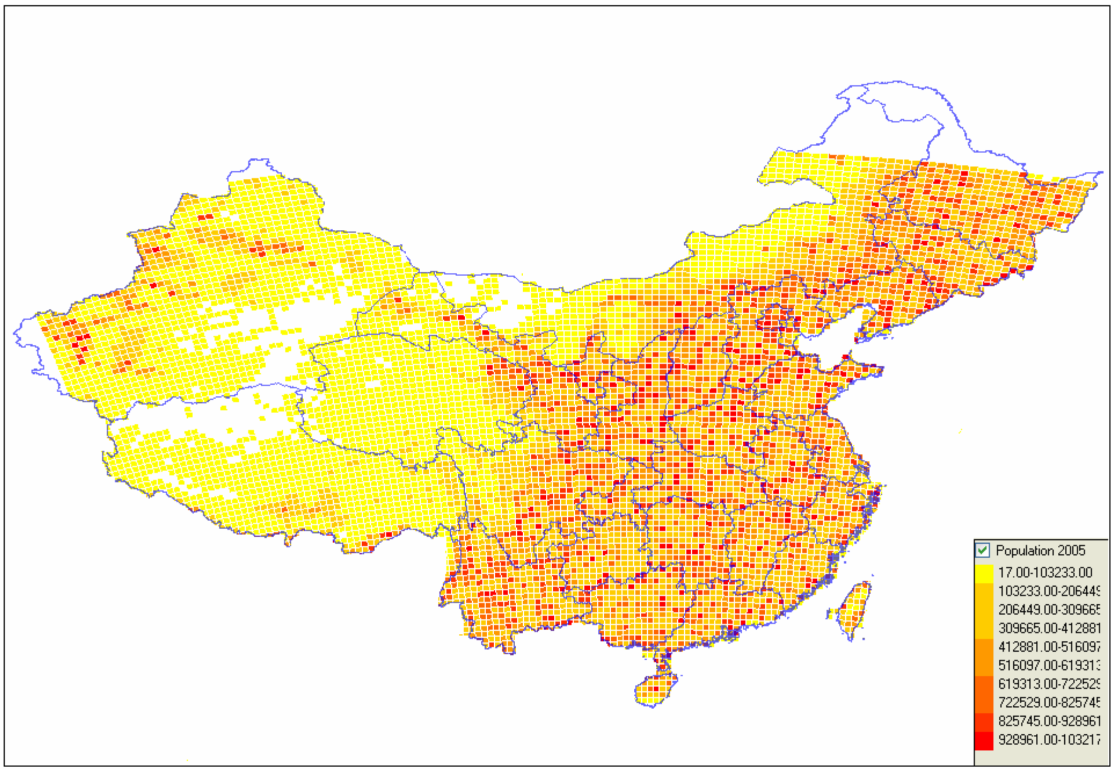


Figure 6-2 Population density and distribution in China in 2005

In this health benefit analysis, the exposed population is the whole population, including residents living in urban and rural areas in China. However, ambient pollution levels in the rural area are unclear because there are few air monitoring stations located there. Some studies in China have shown that indoor air pollution is a more important factor in rural areas, and the characteristics of rural outdoor air pollution may be different from that of urban areas. However, rural residents are still exposed to ambient air pollution which was modeled by CMAQ, and estimates of their health impact from this pollution are included in this analysis. Some uncertainty will exist in the final assessment because most of the concentration-response coefficients and economic valuation coefficients are mainly based on studies conducted in urban areas.

6.1.2 Health outcomes in the benefit analysis

Exposure to outdoor air pollution is associated with a broad spectrum of acute and chronic health effects ranging from irritant effects to death. According to the WHO definition of health, all of these outcomes are potentially relevant for health benefit analysis. Recently, the American Thoracic Society identified a broad range of respiratory health effects associated with air pollution that should be considered “adverse,” spanning outcomes from deaths of respiratory diseases to reduced quality of life and including some irreversible changes in physiologic function. Among the broad categories of health outcomes including mortality and morbidity, there is a wide variety of specific outcomes that could be assessed and should be considered for health benefit analysis. Selection of health outcomes ultimately depends on the objective of the health benefit analysis.

In this assessment, our objective is to evaluate the health benefits from various energy scenarios compared to the baseline scenario and propose some suggestions to the decision maker on policy and technology. The choice of health outcomes in the assessment is restricted in the availability of the concentration-response functions and incidence data. The human health outcomes evaluated in our assessment include:

- Mortality
  - Mortality, long-term, all cause
  - Mortality, cardiopulmonary disease
  - Mortality, lung cancer
- Morbidity
  - Hospital admissions, respiratory disease
  - Hospital admissions, cardiovascular disease
  - Outpatient visits for all cause

6.1.3 Baseline incidence and prevalence

In the present assessment, 2001 was selected as the baseline year for the health benefits estimation. The national level mortality rates associated with specific causes are from 2001 Chinese Health Statistical Yearbook[2] (see table 6-2), and the incidence rates of disease treatment events (including hospital admissions and outpatients or emergency room visits) are from the National Health Services Survey in 2003[3].

In the present assessment, the same incidence rate was applied to the whole country due to lack of other available data; this may increase the uncertainty of the results. In future studies, more information should be collected and geographic information system should be used to apply more geographically specific

[2] 2001 Chinese Health Statistical Yearbook. Ministry of Health, China. Peking Union Medical College Press. 2001

[3] An Analysis Report of National Health Services Survey in 2003. Center For Health Statistics and Information, MOH. Peking Union Medical College Press. 2004

incidence rates, with the intent of increasing the accuracy of the analysis.

It was assumed that the baseline mortality or incidence would be stable during the whole study period due to lack of available projected incidence rates for cause-specific mortality and morbidity. Based on these assumptions, the health benefits are estimated by comparing incidence in the two mitigation scenarios to incidence under the BAU scenario.

Table 6-2 National mortality and morbidity rates in China for selected health endpoints in 2001

Health Endpoints	Incidence (per person per year)
Mortality for all-cause	0.0058
Mortality for cardiopulmonary	0.0032
Mortality for lung cancer	0.0003
Hospital admissions for respiratory disease	0.0042
Hospital admissions for cardiovascular disease	0.0062
Outpatient visits for all cause	3.4788

6.1.4 Construction of concentration-response functions

6.1.4.1 Concentration-response studies for particulate matter and mortality

The effects of air pollution on human health include chronic effects of long-term exposure and acute effects of short-term exposure. In the past two decades, a large number of studies have reported the concentration response relationship between air pollution exposure and human health, mostly through short-term time-series studies. Long-term cohort studies are best for evaluating the effects of chronic exposure to air pollution on human health, and time-series studies are used to analyze the acute effects of short-term high levels of air pollutants. It is possible that the long-term human health effects derived from cohort studies may overlap with the short-term effects from the time-series studies (Eftim and Dominici 2005; Thomas 2005).

A large number of time-series studies have been published in the past twenty years, but results from only a few cohort studies are reported. In China, there are some time-series studies on air pollution on human health and several ecological comparative studies and cross-sectional studies, which were conducted in large cities, such as Beijing (Xu, Gao et al. 1994), Shanghai (Kan and Chen 2003; Kan, Chen et al. 2003), and Shenyang (Xu, Yu et al. 2000).

Cohort studies take advantage of spatial variation in air pollution concentration to compare incidence of disease and death in populations exposed to differing levels of air pollution over a long period of time. By following large populations for many years, cohort studies estimate both numbers of deaths and, more importantly, mean reduction in life span attributable to air pollution.

Evidence from cohort studies in the United States indicates that long-term exposure to outdoor air pollution is associated with increases in all-cause mortality and cardiopulmonary mortality in adults. These cohort studies include mainly the Harvard Six-city Study (Dockery, Pope et al. 1993), the ACS cohort study (Pope, Thun et al. 1995), and the ACS extended study (Pope, Burnett et al. 2002).

6.1.4.2 Concentration-response studies for particulate matter and morbidity

Time-series studies have been conducted to analyze the daily rate of health events, such as hospital admissions or death, in one or more locales in relation to contemporaneous daily concentrations of air pollutants and other risk factors (e.g., weather). In the time-series studies, individual factors, such as smoking, nutrition, behavior and genetic characters, are unlikely to be confounders because they are not generally associated day to day with daily concentrations of air pollution. Regression techniques are used to estimate a coefficient that represents the relationship between air pollutant concentrations and human health outcomes. The usual regression methods model the logarithm of the response variable, such as daily deaths or hospital admissions, to estimate the relative risk or proportional change in the outcome per increment of ambient pollution concentration.

In this assessment, the short-term effects on mortality from acute exposure to air pollution were not included in order to avoid the double-counting question.

6.1.4.3 Transformation of PM_{10} and $PM_{2.5}$ functions

Studies report health outcomes in relation to concentrations of TSP, PM_{10}, and $PM_{2.5}$. The concentration-response functions derived from studies indexing TSP and PM_{10} require a conversion to index $PM_{2.5}$ to be consistent with the ambient concentration data. Ostro (2005) suggests that the best estimation of the $PM_{2.5}$/ PM_{10} ratio would come from a local study, as it would capture all the local conditions and sources of pollution. Aunan and Pan (2004) assert that the ratio of PM_{10} to TSP is 0.60. Qian et al. (2001) reported the ratio in the range of 0.51~0.72 for urban areas in four Chinese cities. The ratio of $PM_{2.5}$ to PM_{10} that Cohen (2005) recommended for heath impact assessments is 0.5 for developing countries; this is similar to the value reported from Chinese studies. In this national assessment, a conversion ratio of 0.60 for $PM_{2.5}$ to PM_{10} was applied and a ratio of 0.50 for PM_{10} to TSP was applied.

6.1.4.4 Construction of the C-R functions from the selected studies

The relationship between the concentration of a pollutant (x), and the population response (y), is called the concentration-response (C-R) function. C-R functions are estimated from epidemiological studies. The statistic model and the related parameters are estimated for the C-R function based on both the air pollution data (e.g., average daily $PM_{2.5}$ concentration) and the health outcomes data (e.g., daily cause-specific deaths). Several different models, such as general linear model, log-linear model, logistic model, and Cox proportional risk model, are often used in the epidemiological studies.

For the benefits estimation, more concern was placed on the relationship between the change of the pollutant level, △x, and the corresponding change of the health response in the exposed population, △y, rather then the C-R function itself. There is interest in understanding the mortality and morbidity avoided if the concentration of a pollutant is reduced by 10 μg/m^3. The relationship between Δx and Δy can be derived from the C-R function, although the derivation process is different for different functional forms. The derivation of the relationship of interest for BenMAP is discussed in appendix D of the BenMAP technical appendices.

The most common functional form is the log-linear model, in which the natural logarithm of the health response is a linear function of the pollutant concentration. The most common index for association between air pollutant and health outcome is the relative risk (RR) associated with a given change of the pollutant concentration (e.g., 10 μg/m^3 increase in $PM_{2.5}$). The process of the derivation for the log-linear model is discussed as follows:

The log-linear relationship defines the incidence rate (y) as:

$$y = B \cdot e^{\beta \cdot PM} \quad \text{or} \quad \ln(y) = \alpha + \beta \cdot PM$$

Where the parameter B denotes the incidence rate of y when the concentration of PM is zero, the parameter β is the coefficient of PM, ln(y) is the natural logarithm of y, and $\alpha = \ln(B)$.

The relationship between ΔPM and Δy is:

$$\Delta y = y_c - y_0 = e^{\beta \cdot PM_0}\left(e^{\beta \cdot (PM_C - PM_0)} - 1\right) = y_0 \cdot \left(e^{\beta \cdot \Delta PM} - 1\right)$$

Here, y_0 denotes the baseline incidence rate of the health effect (i.e., the incidence rate before the change in PM). The change in the incidence of adverse health effects can then be calculated by multiplying the change in the incidence rate, Δy, by the relevant population.

Epidemiological studies often report a relative risk for a given ΔPM, rather than the coefficient (β). The relative risk is the ratio of two risks and is also related to the coefficient β as shown here:

$$RR = \frac{y_0}{y_c} = e^{\beta \cdot \Delta PM}$$

So the coefficient in the C-R function underlying the relative risk can be derived as:

$$\beta = \frac{\ln(RR)}{\Delta PM}$$

The final concentration-response functions applied in BenMAP are shown in in Table 6-3.

6.1.4.5 Threshold for Particulate Matter

According to the WHO report (WHO 2000), there is no lower bound under which particulate matter may not impact the health of susceptible populations. In this assessment, it was assumed that there is no threshold concentration for the particulate matter effects.

6.1.4.6 Limitation and uncertainty

In this assessment, the exposure-response functions derived from the United States-based cohort studies were adopted to estimate mortality impacts from air pollution, and the regression coefficients derived from short-term time-series studies in large cities in China were used to estimate acute impacts from air pollution. The use of coefficients from different countries may introduce uncertainty in the estimation; however, data availability governed the overall choice of concentration response data. Some results were adopted from the United States due to the lack of the relevant Chinese research, especially for the long-term mortality outcomes. Premature deaths are the most severe health outcome due to air pollution, and economic gains due to reduction of air pollution on premature deaths constitute the great majority of the total. As such, it would have greatly underestimated the impact of air pollution on health in China if this component was omitted due to lack of local data.

Another issue is the shape of the concentration-response curve and the threshold. Some results in the United States and European cities reported that shape of the concentration-response curve for particulate matter and mortality is linear or logarithmic linear, and there is no threshold level below which the ambient particulate matter have no effect on mortality. No relevant studies have been conducted in China, and the shape of concentration-response curve and the relevant threshold remain unclear.

Due to the limitation of population distribution data, the age-specific population size for each GIS grid could not be estimated. Thus the health benefits and economic gains for specific age groups cannot be assessed and instead the concentration-response coefficients for specific age group are generalized to the whole populations.

Finally, the exposed population is the whole population in China, including residents living in urban areas and rural areas. As some experts reported in China, indoor air pollution is a more important issue in rural areas than outdoor air pollution. Generalizing the concentration-response function derived from the studies conducted in the urban areas to the rural areas will add to the uncertainty of the benefit analysis.

Table 6-3 Concentration-response functions applied in BenMAP to estimate morbidity and mortality associated with PM2.5 concentrations

Endpoint	Source	Location	Age	Beta[1]	Std Error	Functional Form	Function for calculation of health effects
All Cause	Pope, Burnett et al. 2002	U.S. 61 cities	30+	0.004018	0.001642	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
All Cause	Pope, Burnett et al. 2002	U.S. 51 cities	30+	0.006015	0.002257	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
Cardiopulmonary	Pope, Burnett et al. 2002	U.S. 61 cities	30+	0.005733	0.002167	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
Cardiopulmonary	Pope, Burnett et al. 2002	U.S. 51 cities	30+	0.008893	0.002914	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
Lung Cancer	Pope, Burnett et al. 2002	U.S. 61 cities	30+	0.007881	0.003463	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
Lung Cancer	Pope, Burnett et al. 2002	U.S. 51 cities	30+	0.012663	0.004265	Log-linear	-(EXP(-Beta*DELTAQ)-1)*Incidence*POP
Hospital admissions for cardiovascular disease[a]	Wong, Lau et al. 1999	Hong Kong	All	0.000997	0.000380	Log-linear	(EXP(Beta*DELTAQ)-1)*Incidence*POP
Hospital admissions for cardiovascular disease[a]	Wong, Atkinson et al. 2002	Hong Kong	All	0.001163	0.000338	Log-linear	(EXP(Beta*DELTAQ)-1)*Incidence*POP
Hospital admissions for respiratory disease[a]	Wong, Lau et al. 1999	Hong Kong	All	0.002646	0.000502	Log-linear	(EXP(Beta*DELTAQ)-1)*Incidence*POP
Hospital admissions for respiratory disease[a]	Wong, Atkinson et al. 2002	Hong Kong	All	0.001658	0.000421	Log-linear	(EXP(Beta*DELTAQ)-1)*Incidence*POP
Outpatient visits for all cause[b]	Xu, Li et al. 1995	Beijing	All	0.000383	0.000140	linear	Beta*DELTAQ*Incidence*POP

1. For the linear functions, beta [=] 1/(μg/m^3 change in $PM_{2.5}$) and for the linear function beta [=] percent change of incidence rate (Table 6-2) per 1μg/m^3 increase of $PM_{2.5}$.

a. In this case, the transformation ratio between $PM_{2.5}$ and PM_{10} is 0.60.

b. In this case, the transformation ratio between $PM_{2.5}$ and PM_{10} is 0.60 and the transformation ratio between PM_{10} and TSP is 0.50.

6.1.4.7 Pooling methods

For this study, the underlying beta values for the same pollutant-health endpoints were not pooled by meta-analysis methods. Instead, the random/fixed effects weights method provided by the BenMAP model was used to calculate the incidence changes using data from all studies shown in table 6-3. More details of the random/fixed effects weights methods are described in the BenMAP technical appendices.

6.2 Results

The quantitative assessment of health benefits resulting from changes in air pollution was completed by applying the BenMAP model under different concentration profiles resulting from the policy scenarios. These concentrations were used with the concentration-response functions relating air pollution and health endpoints. The health benefits resulting from the different policy scenarios are expressed as the avoided health effects when compared with incidence under the BAU (business as usual) scenario.

Table 6-5 presents the estimated number of avoidable health effects for each endpoint under different energy scenarios. Compared with the BAU scenario, improvement of air quality under Scenario 1 will avoid 4600 premature deaths in 2005, 25,000 premature deaths in 2020 and 36,000 premature deaths in 2030. Comparing Scenario 2 to BAU, the avoidable premature deaths are 7500 in 2005, 54,000 in 2020 and 120,000 in 2030.

Figures 6-3 to 6-8 present the estimated health benefits for different health endpoints under different scenarios compared with BAU scenario in target years for all cause mortality, cardiovascular hospital admissions, respiratory hospital admissions and outpatient visits, respectively. As shown by these figures and table 6-5, the health benefits in scenario 2 (BAU+CCP+PCP) are greater than those achieved under scenario 1 (BAU+CCP).

As the figures show, the health benefits of both scenarios are greater in 2010 than in 2020. This follows directly from the trend of $PM_{2.5}$ concentrations between years which is described in Chapter 5.

Table 6-5 Health benefits estimates: numbers of cases avoided in different scenario compared with BAU scenario in target years

Year	Endpoint Group	Endpoints	Scenario 1 (BAU+CCP)			Scenario 2 (BAU+CCP+PCP)		
			Mean	lower	upper	Mean	Lower	Upper
2005	Mortality	All cause	4,595	781	9,035	7,475	1,270	14,693
		Cardiopulmonary	3,720	806	7,093	6,051	1,312	11,533
		Lung cancer	461	52	885	750	84	1,439
	Morbidity	Respiratory	1,147	473	1,921	1,866	771	3,127
		Cardiovascular	1,473	594	2,402	2,397	966	3,909
		Outpatient visits	226,159	64,399	387,918	368,031	104,798	631,265
2010	Mortality	All cause	53,533	9,125	104,728	106,118	18,158	206,441
		Cardiopulmonary	43,260	9,418	81,914	85,586	18,726	160,796
		Lung cancer	5,348	603	10,164	10,554	1,199	19,829
	Morbidity	Respiratory	13,430	5,542	22,518	26,780	11,044	4,4939
		Cardiovascular	17,262	6952	28,197	34,448	13,858	56,372
		Outpatient visits	2,646,077	753,477	4,538,678	5,269,954	1,500,633	9,039,275
2020	Mortality	All cause	25,108	4,271	49,263	54,198	9,238	106,038
		Cardiopulmonary	20,311	4,410	38,617	43,800	9,535	82,945
		Lung cancer	2,515	282	4,807	5,415	610	10,293
	Morbidity	Respiratory	6,280	2,592	10,524	13,595	5,610	22,794
		Cardiovascular	8,068	3,251	13,166	17,474	7,037	28,542
		Outpatient visits	1,237,999	352,523	2,123,475	2,678,650	762,753	4,594,549
2030	Mortality	All cause	36,161	6,157	70,857	121,726	20,834	236,705
		Cardiopulmonary	29,239	6,356	55,488	98,161	21,485	184,311
		Lung cancer	3,618	407	6,898	12,103	1,376	22,719
	Morbidity	Respiratory	9,057	3,738	15,181	30,732	12,672	51,573
		Cardiovascular	11,638	4,688	19,001	39,532	15,903	64,701
		Outpatient visits	1,784,991	508,281	3,061,702	6,046,988	1,721,896	10,372,082

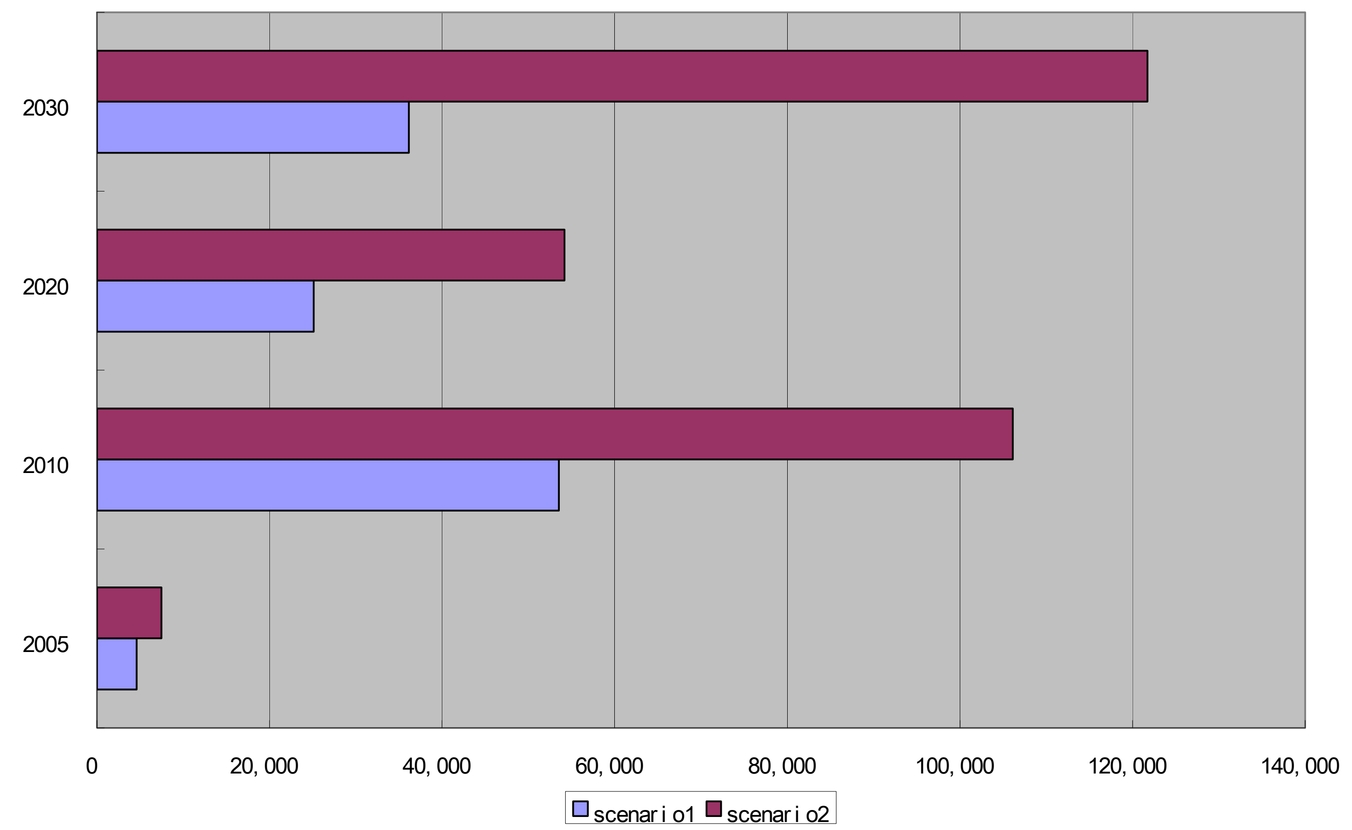


Figure 6-3 Avoided premature deaths in different scenarios compared with BAU scenario in future years

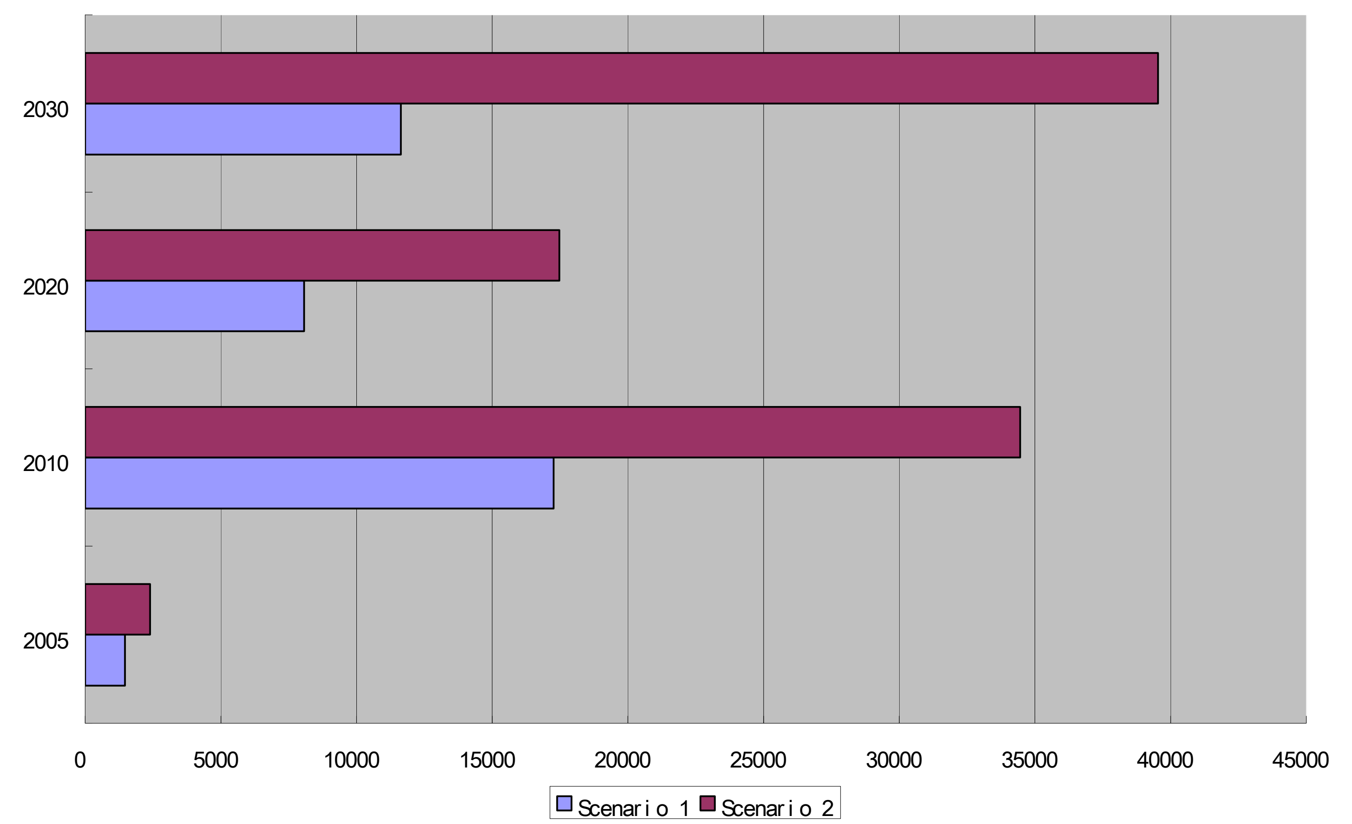


Figure 6-4 Avoided cardiovascular hospital admissions in different scenarios compared with BAU scenario in future years

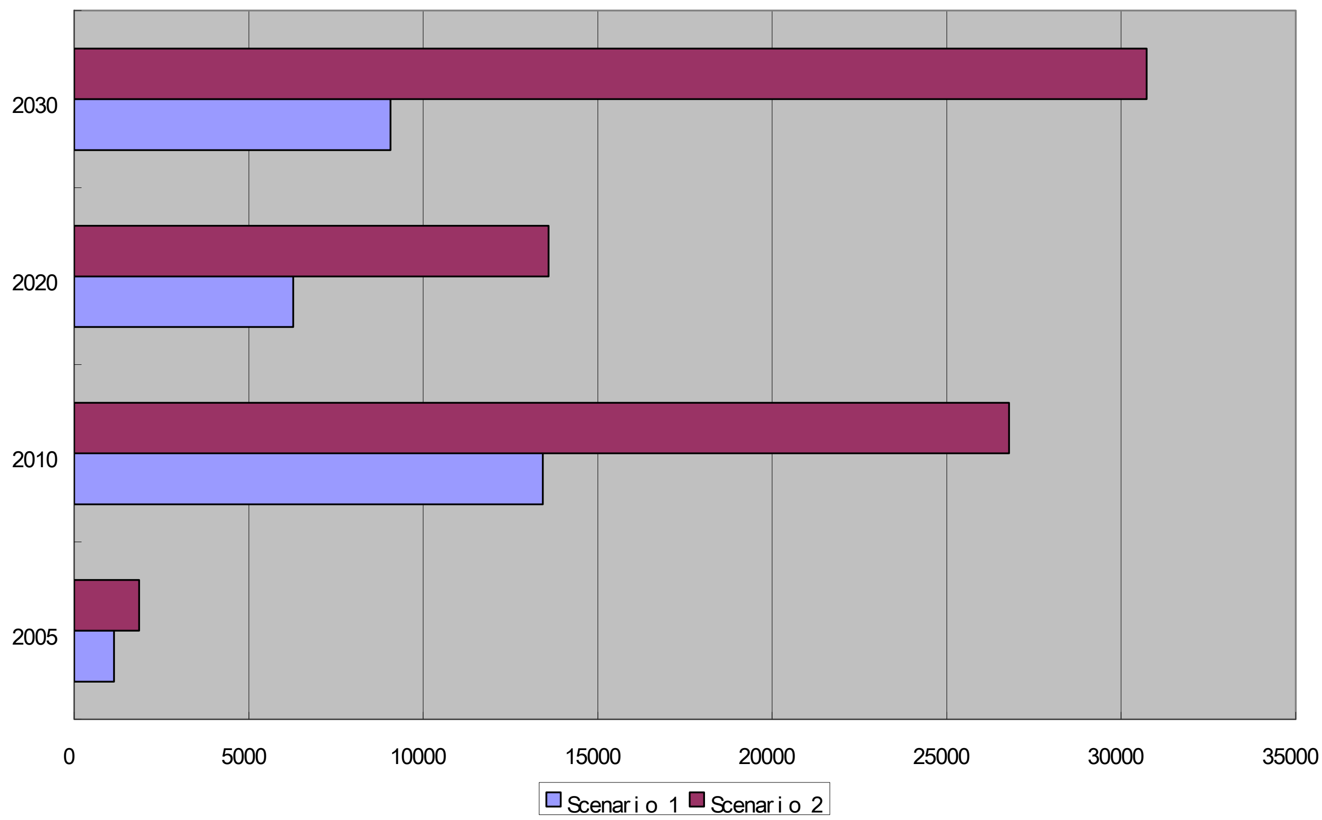


Figure 6-5 Avoided respiratory hospital admissions in different scenarios compared with BAU scenario in future years

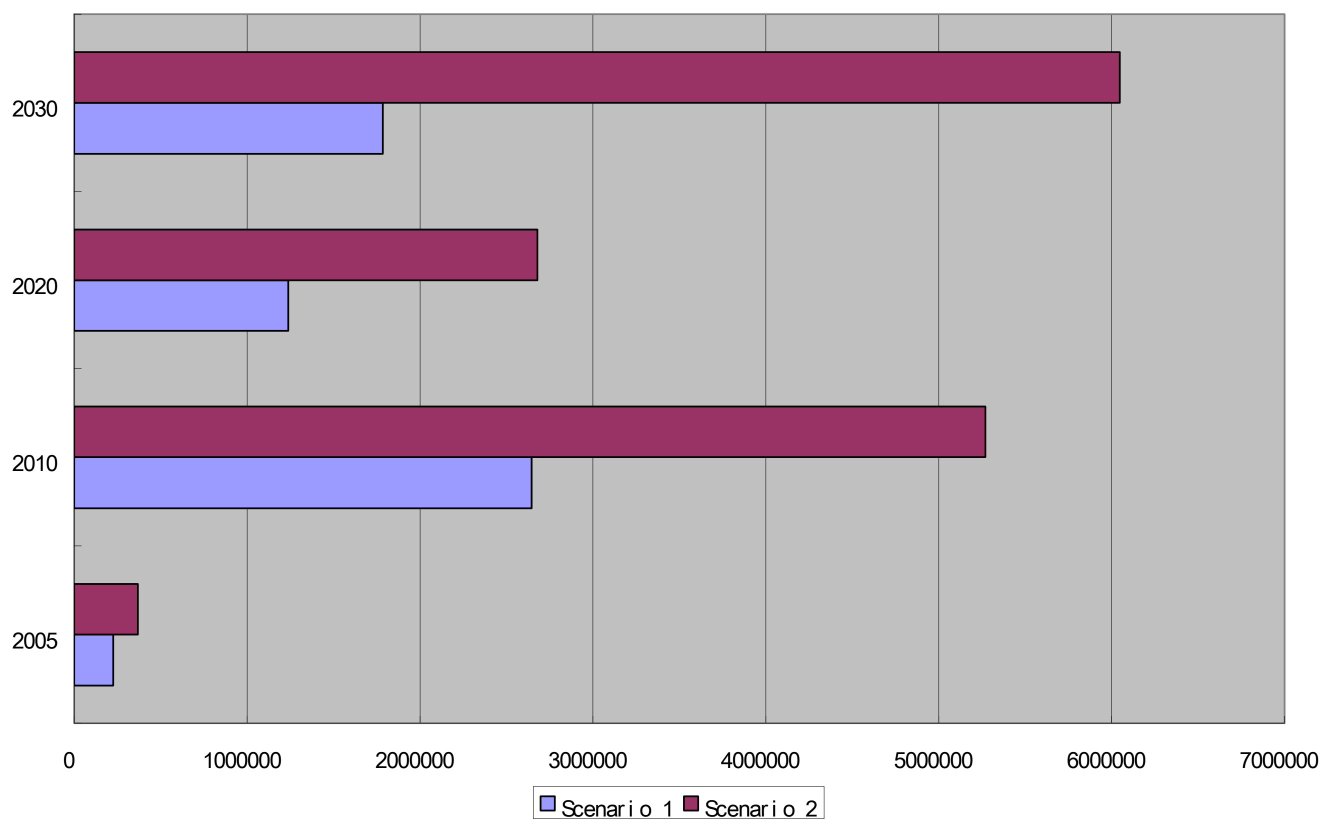


Figure 6-6 Avoided outpatient visits in different scenarios compared with BAU scenario in future years

CHAPTER 7 VALUATION ANALYSIS OF HEALTH EFFECT

7.1 Methodology and data

The economic gain from the health benefits of air pollution reduction resulting from energy/environmental interventions in the target years can be estimated based on the following function：.

$$EG_t = \sum (HEP_{ibt} - HEP_{ist}) * EV_{it}$$

EG: economic gain at different energy/environmental scenarios
HEP: health benefit for different health endpoints
EV: economic value
i: type of health endpoints
b: base case values
s: scenario values
t: target years

There are two major approaches to estimate the value of health effects of air pollution: the cost of illness approach and the willingness to pay (WTP) approach. The cost of illness approach values mortality and morbidity impacts simply as the lost productivity estimated by discounted lost wages plus medical expenditures. Although the cost of illness approach is convenient to be estimated, it does not capture the value of health itself.

Contingent valuation (CV), one of the WTP approaches, is frequently used and considered to be a more appropriate method to evaluate goods that have no-market value, such health status and human life. Sometimes, when WTP estimates are not available, WTP is approximated by other measures, most notably cost of illness measures. But because the cost of illness method does not include the value of avoiding the pain and suffering from the illness (a potentially large component), it is generally believed to underestimate the total value of avoiding the illness, perhaps substantially.

7.1.1 Economic valuation functions for mortality

In China, there are a few studies which use the contingent valuation (CV) method for the valuation of health endpoints. Wang and Mullahy (Wang and Mullahy 2006) conducted such a study in Chonqing, China using the CV method to quantify the economic value of mortality endpoints. The value of statistical life ($VSL_{Chongqing}$) found for Chongqing was used to estimate the value of statistical life for the total population of China. The estimated values of statistical life in China (VSL_{China}) in target years are shown in table 7-2.

Table 7-2 describes the estimated value of statistical life for mortality (VSL_{China}) in the future years based on the Chongqing contingent valuation study. The estimated value of $VSL_{China,t}$ is equal to the predicted future [GDP per capita]$_t$ in target year (*t*) multiplying the ratio between $VSL_{Chongqing}$ and $GDP_{Chongqing}$ in Chongqing. The GDP per capita prediction is based on the annual increase rates of 6.32% during 2005~2010, 6.01% during 2010~2020, and 5.11% during 2020~2030 （Table 3-1). As demonstrated in table 7-2, the predicted GDP per capita in China will reach $2041.84 in 2010, $2247.52 in 2020, and $2271.87 in 2030 in 2005 USD.

Table 7-1 Prediction results of the WTP for saving a statistical life (in 1998 $)

	VSL (1998 RMB)	Std for VSL (1998 RMB)	VSL (2005 USD)	Std for VSL (2005 USD)
Average WTP for saving a statistical life	286,000.00	16,326.00	61,079.79	3486.67

Source: Willingness to pay for reducing fetal risk by improving air quality: A contingent valuation study in Chongqing, China.(Wang and Mullahy 2006)

Table 7-2 Estimated value of statistical life (VSL) for mortality in China (in 2005 $)

Year	GDP per capita growth rate (%)	GDP per capita (2005 USD)	VSL (2005 USD)
2001		1501.73	91694.31
2005	6.32	1918.59	117,146.96
2010	6.32	2041.84	124,672.40
2020	6.01	2247.52	137,231.37
2030	5.11	2271.87	138,717.90

Note: 1. GDP per capita data in 2001 is from 2002 Chinese Statistical Yearbook. The value is computed with the comparative price in 2005 and the average change rate between U.S. Dollar and RMB, 8.00.

2. The estimated $VSL_{China,t}$ value for statistical life for mortality = predicted GDP per capita * (VSL in Chongqing/GDP per capita in Chongqing).

3. GDP per capita growth rate = (GDP growth rate – Population growth rate)/ (1+ Population growth rate)

4. The numbers in 2010, 2020 and 2030 have been adjusted into ones in comparative price in 2005 with the discount rate, 5%.

7.1.2 Economic evaluation functions for morbidity

The value of non-fatal health endpoints was estimated with the cost of illness as there was a lack of information for the WTP methods. The medical expenditures per hospital admission and per hospital outpatient visit (direct cost) and non-medical costs due to health service utilization (indirect cost) were collected from the 1998 National Health Services Survey conducted by the Ministry of Health of China[4]. The direct cost and indirect cost for respiratory or cardiovascular hospital admission were not disaggregated in the 2003 National Health Services Survey report[5], but rather provided as an aggregate unit cost. The unit value of cost of illness was estimated for 2001 based on the annual growth rate of 10.82% for hospital admissions and 13.29% for outpatient visits. The same respective growth rates were used to estimate the unit value of each morbidity endpoint in future years. As table 7-3 shows, the unit value for respiratory hospital admissions, cardiovascular hospital admissions and outpatient visits will reach $1950.40 in 2030, $4468.15 in 2030 and $132.78 in 2030, respectively.

[4] Research on National Health Services - An Analysis Report of the Second National Health Services Survey in 1998. Ministry of Health People's Republic of China. 1999.

[5] An Analysis Report of National Health Services Survey in 2003. Center For Health Statistics and Information, MOH. Peking Union Medical College Press. 2004

Table 7-3 Estimated value of the cost per unit health endpoint (in 2005 $)

Year	Health Endpoint	Cost of Illness
2001	Respiratory Hospital Admissions	335.68
	Cardiovascular Hospital Admissions	769.01
	Outpatient Visits	10.50
2005	Respiratory Hospital Admissions	506.29
	Cardiovascular Hospital Admissions	1159.86
	Outpatient Visits	17.29
2010	Respiratory Hospital Admissions	663.05
	Cardiovascular Hospital Admissions	1518.98
	Outpatient Visits	26.00
2020	Respiratory Hospital Admissions	1137.20
	Cardiovascular Hospital Admissions	2605.19
	Outpatient Visits	58.75
2030	Respiratory Hospital Admissions	1950.40
	Cardiovascular Hospital Admissions	4468.15
	Outpatient Visits	132.78

Note: The unit value of cost of illness was estimated based on the annual growth rate of 10.82% for hospital admissions and 13.92% for outpatient visits.

The unit value of cost illness was discounted at the rate of 5% into the comparative value in 2005.

7.2 Results

The estimated monetary value of the avoidable health effects for each of the study scenarios for future years, 2005, 2010, 2020, and 2030, can be found in Table 7-4. Tables 7-5 and 7-6 display the estimated economic gain of health effects of air pollution in different scenarios in target years by per capita and percentage of GDP, respectively. The estimated economic gain from avoided health effects due to reduced air pollution levels in 2005 under Scenario 1 (BAU+CCP) is expected to be $0.41 per capita, which is about 0.02% of GDP per capita in 2005; the value under Scenario 2 (BAU + CCP + PCP) is $0.66, which is about 0.03% of GDP per capita in 2005. In 2030, the expected value of avoided morbidity and mortality from Scenario 1 is $3.49 per capita in 2005 dollars, which is about 0.05% of GDP in 2030, and the value of avoided morbidity and mortality under Scenario 2 is estimated at $11.76 per capita in 2005 dollars, which is about 0.15% of GDP per capita in 2030.

Table 7-4 The monetary value of health benefits in different scenarios compared with BAU scenario in target years (Million 2005 USD)

Year	Endpoint Group	Endpoint	Scenario 1 (BAU+CCP)			Scenario 2 (BAU+CCP+PCP)		
			Mean value	Lower	Upper	Mean value	Lower	Upper
2005	Mortality	All cause	538.27	91.44	1,058.38	875.68	148.80	1,721.21
		Cardiopulmonary	435.75	94.44	830.98	708.82	153.67	1,351.05
		Lung cancer	54.00	6.04	103.85	87.82	9.83	168.77
	Morbidity	Cardiovascular	1.33	0.55	2.29	2.16	0.89	3.72
		Respiratory	0.75	0.30	1.26	1.21	0.49	2.05
		Outpatient visits	3.91	1.11	6.84	6.36	1.81	11.14
2010	Mortality	All cause	6,690.60	1,140.51	13,089.03	13,262.69	2,269.40	25,801.19

		Cardiopulmonary	5,406.73	1,177.10	10,237.73	10,696.59	2,340.42	20,096.42
		Lung cancer	668.44	75.34	1,272.16	1,319.03	149.85	2,482.34
	Morbidity	Cardiovascular	20.40	8.38	35.13	40.68	16.69	70.10
		Respiratory	11.45	4.61	19.35	22.84	9.19	38.68
		Outpatient visits	66.91	19.05	117.08	133.25	37.94	233.17
2020	Mortality	All cause	3,466.82	589.79	6,802.13	7,483.54	1,275.55	14,641.51
		Cardiopulmonary	2,804.48	608.96	5,332.11	6,047.83	1,316.50	11,452.89
		Lung cancer	347.20	38.97	664.75	747.76	84.26	1,423.32
	Morbidity	Cardiovascular	16.36	6.72	28.16	35.42	14.54	60.99
		Respiratory	9.17	3.70	15.50	19.87	8.00	33.59
		Outpatient visits	66.93	19.06	117.12	144.81	41.24	253.40
2030	Mortality	All cause	5,056.21	860.95	9,907.41	17,020.14	2,913.08	33,096.88
		Cardiopulmonary	4,088.31	888.77	7,758.55	13,725.26	3,004.08	25,770.99
		Lung cancer	505.83	56.88	965.82	1,692.22	192.35	3,181.76
	Morbidity	Cardiovascular	40.47	16.62	69.67	137.31	56.34	236.64
		Respiratory	22.70	9.14	38.36	77.10	31.02	130.59
		Outpatient visits	206.32	58.75	361.04	698.95	199.03	1,223.08

Note: the monetary values were adjusted by the annual discount rate, 5%.

Table 7-5 Per capita economic gain of the health benefits obtained in different scenarios compared with BAU scenario in target years (in 2005 USD)

Year	Endpoint Group	Endpoint	Scenario 1 (BAU+CCP)			Scenario 2 (BAU+CCP+PCP)		
			Per capita	Lower	Upper	Per capita	Lower	Upper
2005	Mortality	All cause	0.4072	0.0692	0.8006	0.6624	0.1126	1.3020
		Cardiopulmonary	0.3296	0.0714	0.6286	0.5362	0.1162	1.0220
		Lung cancer	0.0408	0.0046	0.0786	0.0664	0.0074	0.1277
	Morbidity	Cardiovascular	0.0010	0.0004	0.0017	0.0016	0.0007	0.0028
		Respiratory	0.0006	0.0002	0.0010	0.0009	0.0004	0.0015
		Outpatient visits	0.0030	0.0008	0.0052	0.0048	0.0014	0.0084
2010	Mortality	All cause	4.8553	0.8277	9.4986	9.6246	1.6469	18.7236
		Cardiopulmonary	3.9236	0.8542	7.4294	7.7624	1.6984	14.5838
		Lung cancer	0.4851	0.0547	0.9232	0.9572	0.1087	1.8014
	Morbidity	Cardiovascular	0.0148	0.0061	0.0255	0.0295	0.0121	0.0509
		Respiratory	0.0083	0.0033	0.0140	0.0166	0.0067	0.0281
		Outpatient visits	0.0486	0.0138	0.0850	0.0967	0.0275	0.1692
2020	Mortality	All cause	2.3584	0.4012	4.6273	5.0908	0.8677	9.9602
		Cardiopulmonary	1.9078	0.4143	3.6273	4.1142	0.8956	7.7911
		Lung cancer	0.2362	0.0265	0.4522	0.5087	0.0573	0.9682
	Morbidity	Cardiovascular	0.0111	0.0046	0.0192	0.0241	0.0099	0.0415
		Respiratory	0.0062	0.0025	0.0105	0.0135	0.0054	0.0229
		Outpatient visits	0.0455	0.0130	0.0797	0.0985	0.0281	0.1724
2030	Mortality	All cause	3.3155	0.5646	6.4967	11.1607	1.9102	21.7029
		Cardiopulmonary	2.6809	0.5828	5.0876	9.0002	1.9699	16.8990
		Lung cancer	0.3317	0.0373	0.6333	1.1097	0.1261	2.0864
	Morbidity	Cardiovascular	0.0265	0.0109	0.0457	0.0900	0.0369	0.1552
		Respiratory	0.0149	0.0060	0.0252	0.0506	0.0203	0.0856

Outpatient visits	0.1353	0.0385	0.2367	0.4583	0.1305	0.8020	

Note: the monetary values were adjusted by the annual discount rate, 5%.

Table 7-6 The percentage of GDP gain of the health benefits obtained in different scenarios in target years (in 2005 USD)

Year	Endpoint Group	Endpoint	Scenario 1 (BAU+CCP)			Scenario 2 (BAU+CCP+PCP)		
			GDP percent	Lower	Upper	GDP percent	Lower	Upper
2005	Mortality	All cause	0.0212	0.0036	0.0417	0.0345	0.0059	0.0679
		Cardiopulmonary	0.0172	0.0037	0.0328	0.0279	0.0061	0.0533
		Lung cancer	0.0021	0.0002	0.0041	0.0035	0.0004	0.0067
	Morbidity	Cardiovascular	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
		Respiratory	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
		Outpatient visits	0.0002	0.0000	0.0003	0.0003	0.0001	0.0004
2010	Mortality	All cause	0.1863	0.0318	0.3645	0.3693	0.0632	0.7185
		Cardiopulmonary	0.1506	0.0328	0.2851	0.2979	0.0652	0.5596
		Lung cancer	0.0186	0.0021	0.0354	0.0367	0.0042	0.0691
	Morbidity	Cardiovascular	0.0006	0.0002	0.0010	0.0011	0.0005	0.0020
		Respiratory	0.0003	0.0001	0.0005	0.0006	0.0003	0.0011
		Outpatient visits	0.0019	0.0005	0.0033	0.0037	0.0011	0.0065
2020	Mortality	All cause	0.0505	0.0086	0.0990	0.1090	0.0186	0.2132
		Cardiopulmonary	0.0408	0.0089	0.0776	0.0881	0.0192	0.1667
		Lung cancer	0.0051	0.0006	0.0097	0.0109	0.0012	0.0207
	Morbidity	Cardiovascular	0.0002	0.0001	0.0004	0.0005	0.0002	0.0009
		Respiratory	0.0001	0.0001	0.0002	0.0003	0.0001	0.0005
		Outpatient visits	0.0010	0.0003	0.0017	0.0021	0.0006	0.0037
2030	Mortality	All cause	0.0431	0.0073	0.0844	0.1451	0.0248	0.2821
		Cardiopulmonary	0.0348	0.0076	0.0661	0.1170	0.0256	0.2197
		Lung cancer	0.0043	0.0005	0.0082	0.0144	0.0016	0.0271
	Morbidity	Cardiovascular	0.0003	0.0001	0.0006	0.0012	0.0005	0.0020
		Respiratory	0.0002	0.0001	0.0003	0.0007	0.0003	0.0011
		Outpatient visits	0.0018	0.0005	0.0031	0.0060	0.0017	0.0104

Note: the monetary values were adjusted by the annual discount rate, 5%.

Figures 7-1 to 7-6 present the estimated monetary value of the avoidable health effects for the different scenarios in future years for all cause mortality, cardiovascular hospital admissions, respiratory hospital admissions and outpatient visits, respectively. It is apparent that pollution control policies (PCP) result in greater economic benefits than climate change policies (CCP) in terms of $PM_{2.5}$ related economic benefits.

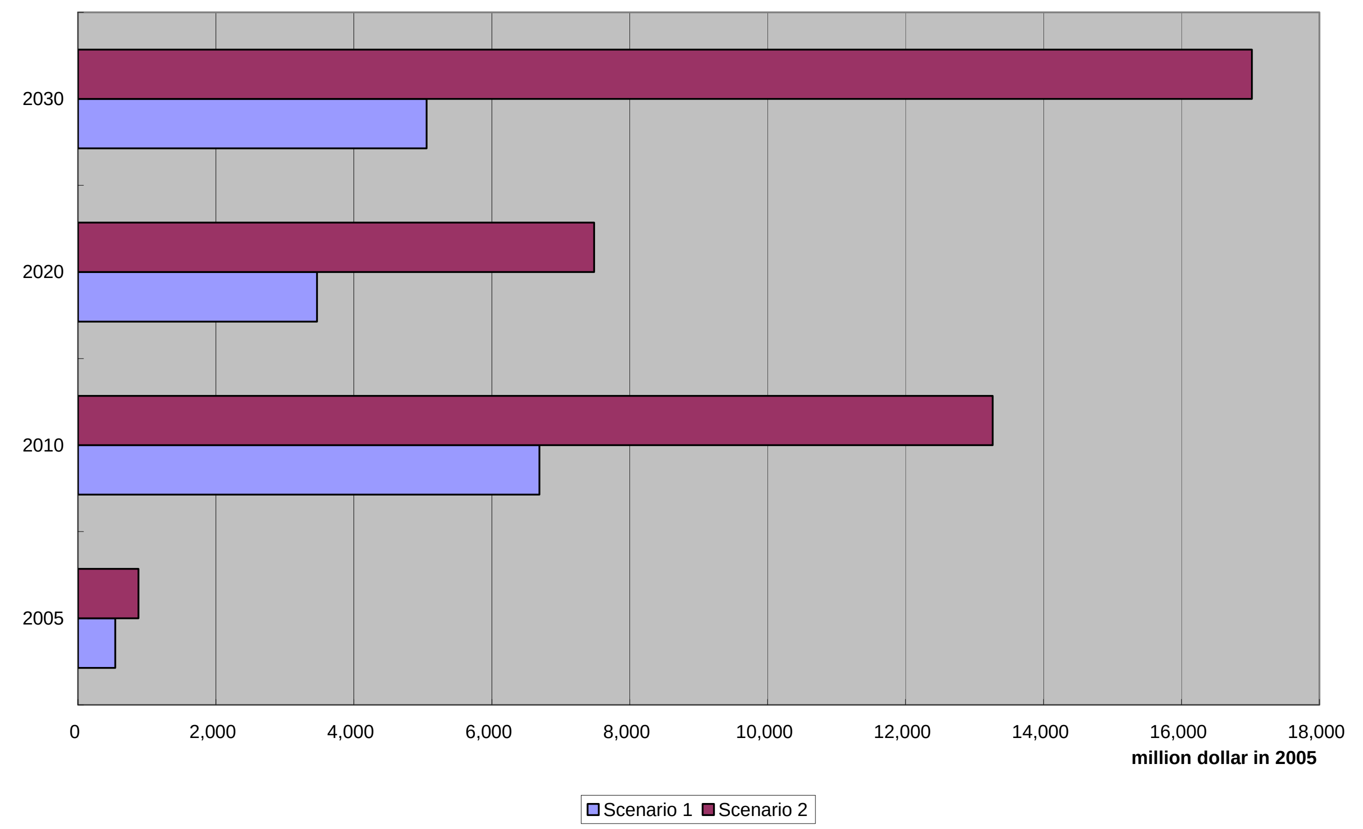


Figure 7-1 Monetary value due to avoided premature deaths in different scenarios compared with BAU scenario in future years

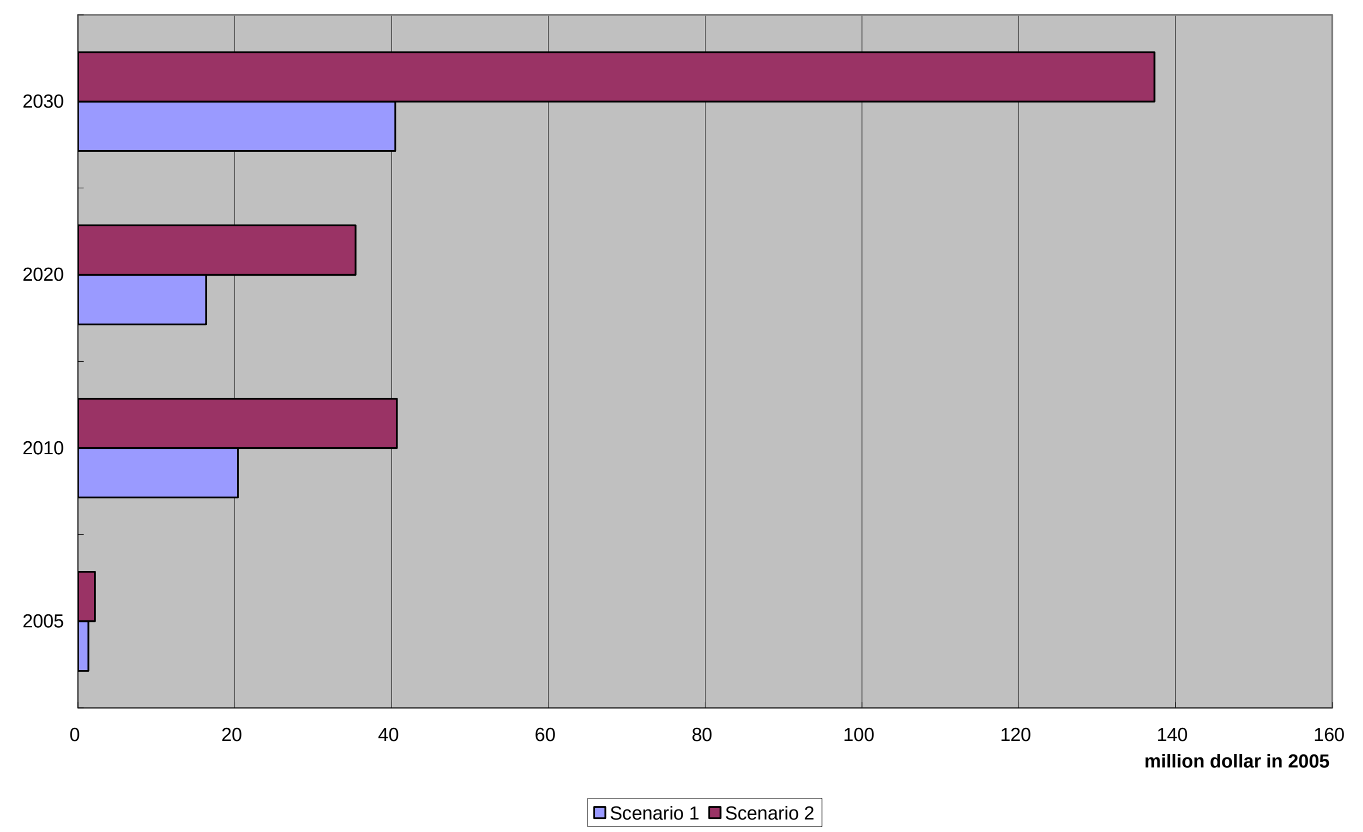


Figure 7-2 Monetary value due to avoided cardiovascular hospital admissions in different scenarios compared with BAU scenario in future years

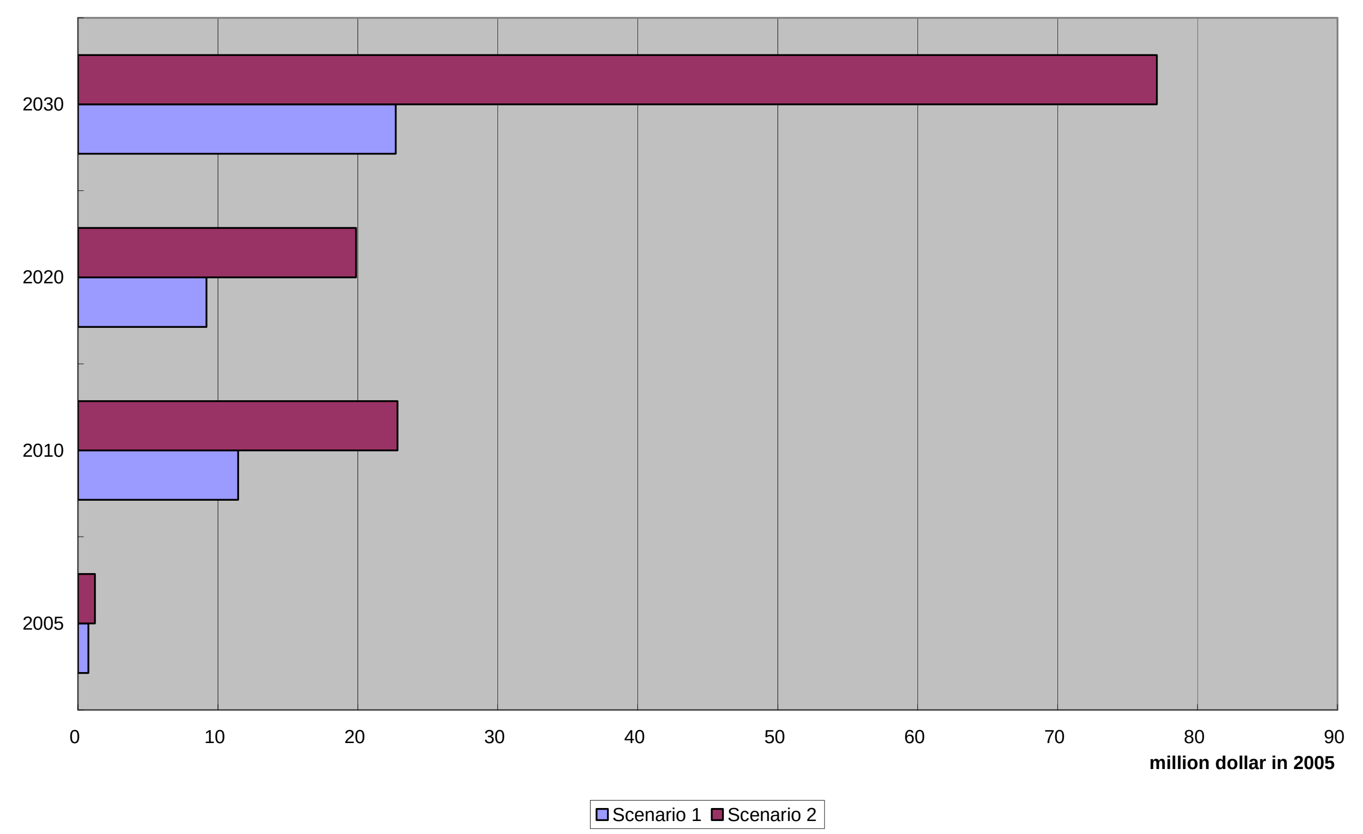


Figure 7-3 Monetary value due to avoided respiratory hospital admissions in different scenarios compared with BAU scenario in future years

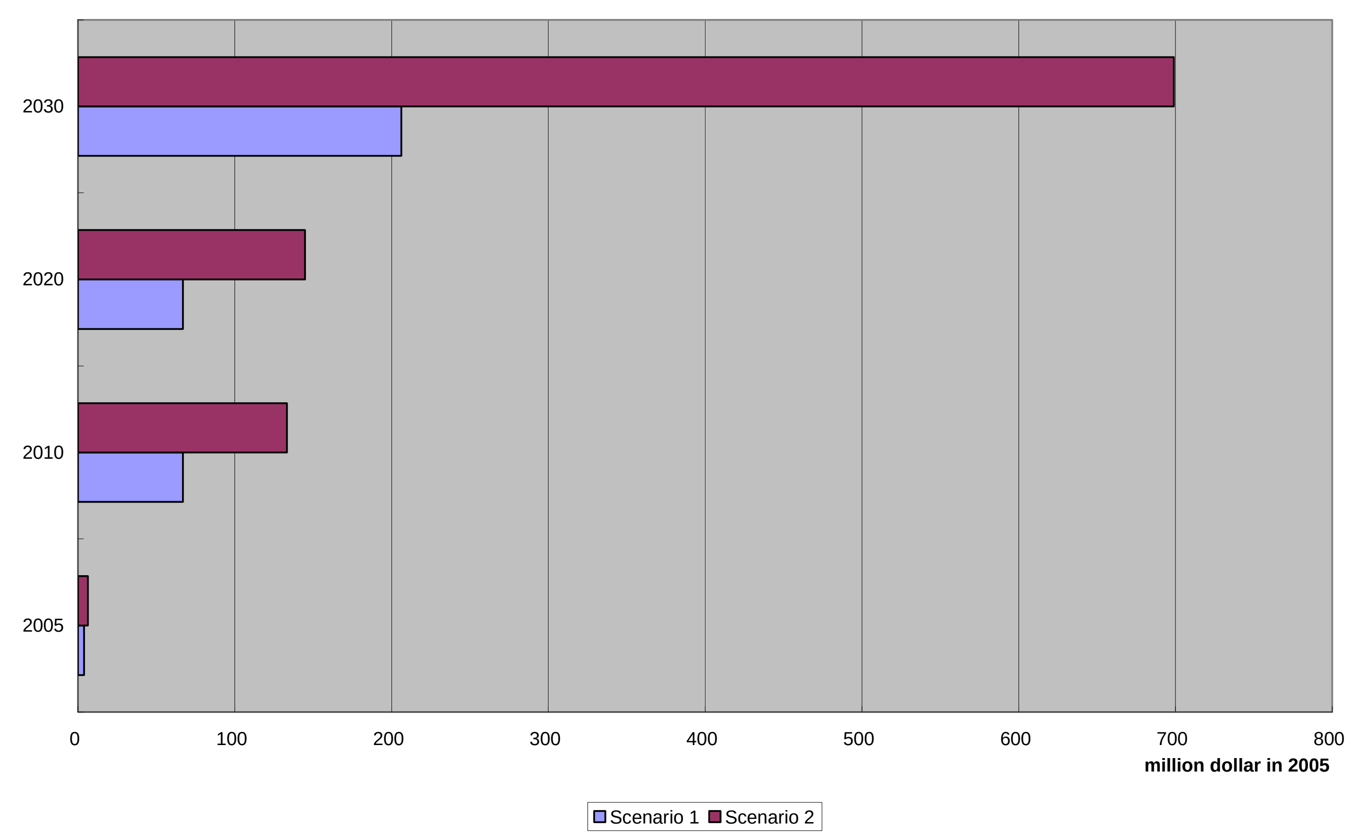


Figure 7-4 Monetary value due to avoided outpatient visits in different scenarios compared with BAU scenario in future years

7.3 Discussion

Based on the results of the health benefits and economic valuation analyses, it is apparent that the implementation of pollutant control policies (PCP) and climate change policies (CCP) not only improve air quality at the national level, but also promote human health by avoiding premature deaths, hospital admissions and outpatient room visits of the exposed population. The results of this study demonstrate the type of impact that government pollution control policy could have on public health.

The results also demonstrate that the integrated implementation of the Pollution Control (PCP) and Climate Change (CCP) Policies (Scenario 2) contributes the most to the improvement of air quality and results in more health benefits and related economic benefits when compared with the separate implementation of either the PCP or CCP.

Premature death is the most severe health outcome from air pollution. In this assessment, one noticeable result is that the benefits or monetary gain from avoiding premature death comprises the majority of the total health benefits realized from avoided air pollution. This result suggests that chronic effects of particulate air pollution, e.g. premature death, have the most serious impacts on human health.

Additionally, the method of assessment should be taken into account. In this study, the willingness to pay method (WTP method) was adopted to estimate the economic value of mortality health endpoints and the cost of illness method for morbidity health endpoints. However, using the VSL (calculated by the WTP method) generally produces larger economic value of morbidity endpoints than with the cost of illness method. Thus, since cost of illness method was used and not the VSL, the economic value of health benefits from morbidity health endpoints may be underestimated.

Lastly, as some studies in China have reported, the chronic health effects of air pollution in China may not be as sensitive as those in the U.S. In this report, the study results for the chronic exposure to air pollution (mortality) in the United States were adopted. Therefore, the avoidable mortality and associated economic value from air pollution reduction may be overestimated.

The only pollutant included in the health benefits methodology was $PM_{2.5}$, which is one of many air pollutants considered harmful to human health. Other pollutants, such as NO_2, SO_2, and O_3, have also been confirmed to have adverse effects on human health. SO_2 is considered to be an important air pollutant in China, especially during the winter season in the North of China. Following the implementation of the climate change policies (CCP) and pollution control policies (PCP), the ambient concentrations of these pollutants would also be expected to be reduced. Taking into account more air pollutants in the benefits analysis and economic valuation would increase the health benefits and economic gains. For the benefits analysis of energy scenarios, considering more pollutants may be preferred. However, it would lead to some troubles, especially double-counting problem.

In conclusion, though certain simplifications were made in the health benefits analysis, such as only evaluating the relationship between PM2.5 and health benefits, this study suggests that the health benefits and economic gains from air pollution reduction can be quantitatively evaluated for the purposes of comparing policy scenarios. Additionally, the previously mentioned simplifications could be further explored and expanded on in future research.

CHAPTER 8 SUMMARY

The results of this research are reviewed in this chapter, followed by implications for policy makers.

8.1 Discussion on overall results

The BAU case forecasts an increase in final energy demand of 2.01 times between 2001 and 2030. Consumption of coal products increases slowly, but heat and electricity, mainly transformed from coal in China, rise faster. Oil and natural gas have much larger increases, while biomass declines 76% during the 30 year period of the analysis. Under BAU, the energy structure continues to operate more sustainably and efficiently, but coal (coal products, heat and electricity transformed from coal, etc.) remains dominant in primary energy demand, representing 54.54% of total energy consumed in 2030.

The result of the emission analysis shows that the energy savings of Scenario 1 are very significant. Energy consumption in Scenario 1 is 11.44 Billion Gigajoules less than the BAU case in 2030. Scenario 2 is not as effective in energy saving because the main purpose of its is to reduce the emissions of air pollutants. These policies do not focus as much on increasing energy efficiency, and some of these policies even need additional energy consumption for emission control of pollutants, e.g. FGD for SO_2 control and baghouse for PM control.

Table 8-1 Summary of emission reduced for scenarios (kTons)

	SO_2	NOx	BC	OC	CO	NMVOC	CO_2
BAU+CCP (Scenario 1)							
2005	547	225	48	149	3284	307	37
2010	1411	619	118	323	7490	776	85
2020	2952	1436	173	418	11,466	1389	194
2030	4703	2376	177	281	11,802	1747	329
BAU+CCP+PCP (Scenario 2)							
2005	765	309	72	190	4944	629	39
2010	1995	995	165	406	12,022	1738	93
2020	6725	3029	276	659	21,711	3635	209
2030	12,018	4874	267	416	17,146	4433	366

The results of air quality modeling show that concentrations of SO_2 are reduced in Scenario 1 and Scenario 2 by the energy efficiency (CCP) and pollutants control policies (PCP) which slow down the growth rate of total energy consumption and control pollutant emissions. The distribution and intensity of concentration benefits of CCP and PCP policies are mostly the same for SO_2. For PM, pollutant control policies (PCP), which control pollutant emissions, have more benefits than CCP policies for $PM_{2.5}$ distribution and intensity. For $PM_{2.5}$ and SO_2 concentrations three heavily polluted areas showed more effects than other areas: the central region including the cities Beijing, Tianjin and Senyang, the eastern Changjiang river delta area including Zhengzhou, Wuhan, Hefei and Nanjing, and the southwestern region including Chongqing and Sichuan..

The result of health effects analysis shows that there are more health benefits in Scenario 2

(BAU+CCP+PCP) than in Scenario 1 (BAU+CCP) compared with BAU scenario. Compared with the BAU scenario, improvement of air quality under Scenario 1 will avoid 4595 premature deaths in 2005, 25,108 premature deaths in 2020 and 36,161 premature deaths in 2030. Under Scenario 2, the avoided premature deaths compared to BAU are 7475 in 2005, 54,198 in 2020 and 121,726 in 2030. The pollutant control policies (PCP) have a greater impact than the climate change policies (CCP) for $PM_{2.5}$ related health benefits.

The results of the valuation of health effects shows that the pollutant control policies (PCP) have more economic benefits than climate change policies (CCP) in $PM_{2.5}$ related economic benefits. The estimated economic gain of health effects from reduced air pollution levels in 2005 under Scenario 1 (BAU+CCP) is expected to be \$0.41 per capita, which is about 0.02% of GDP per capita in 2005. The value under Scenario 2 (BAU + CCP + PCP) is \$0.70, which is about 0.03% of GDP per capita in 2005. In 2030, the expected value of avoided morbidity and mortality from Scenario 1 is \$3.49 per capita in 2005 dollars, which is about 0.05% of GDP in 2030. The value of avoided morbidity and mortality under Scenario 2 is estimated at \$11.76 per capita in 2005 dollars, which is about 0.15% of GDP per capita in 2030.

Table 8-2 Summary of health benefits for scenarios (Monetary mean value, Million Dollar in 2005)

Endpoint/Scenario	Mortality			Morbidity		
	All cause	Cardiopulmonary	Lung cancer	Cardiovascular hospital admission	Respiratory hospital admission	Outpatient visits
BAU+CCP (S1)						
2005	538.27	435.75	54.00	1.33	0.75	3.91
2010	6,690.60	5,406.73	668.44	20.40	11.45	66.91
2020	3,466.82	2,804.48	347.20	16.36	9.17	66.93
2030	5,056.21	4,088.31	505.83	40.47	22.70	206.32
BAU+CCP+PCP (S2)						
2005	875.68	708.82	87.82	2.16	1.21	6.36
2010	13262.69	10696.59	1319.03	40.68	22.84	133.25
2020	7483.54	6047.83	747.76	35.42	19.87	144.81
2030	17,020.14	13,725.26	1692.22	137.31	77.10	698.95

8.2 Summary and policy implications

- Generally, CCP policies are a good choice if it is desirable to reduce emissions of GHG and local/regional pollutants at the same time. PCP policies are efficient to control local/ regional pollutants, but do not have a large impact on GHG abatement. Pollutant control policies (PCP), which control pollutants emissions, have more benefits than climate change policies (CCP) for $PM_{2.5}$ related health benefits. With time, the CCP and PCP policies become increasingly effective in reducing SO_2 and $PM_{2.5}$.
- Active energy policies can create local, national and global environmental benefits as well as significant health benefits. In 2030, active policies (PCP+CCP) can mitigate:
  - 13.2 Billion Gigajoule TCE energy demands,

- 12,018 kt SO_2, 3874 kt NOx, 267 kt BC and 426 kt OC,
- 366 Million Tons Carbon,
- 121,726 deaths,
- $33,351 million total benefits for all health endpoints.

➢ Continued Sustainable Energy Policies are critical for China. The following policies are recommended:
- Initiative on Energy Efficiency Programs.
- Developing a long-term strategy for natural gas and electricity supply.
- Implementing more restrictive vehicle emission standards.
- Comprehensive control strategies on PM_{10} and $PM_{2.5}$: local combustion, fugitive dusts, and regional impact.
- Encouraging the development of new scientific support methodologies for policymaking which can address secondary pollutants ($PM_{2.5}$, Ozone, etc), regional impact, and Multi- effects.

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